GEOCHEMISTRY AND GENESIS OF THE BAUXITE DEPOSIT AROUND YERCAUD, DISTRICT SALEM, TAMIL-NADU

ABSTRACT

THESIS SUBMITTED FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

GEOLOGY

BY

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ABSTRACT

India is very fortunate in having vast and economic deposits of bauxite. In Tamil Nadu State, bauxite occurrences are known in the Salem, Madurai and Nilgiri districts. The most important deposit where present investigations have been carried out is located near Yercaud, Shevaroy hills, district Salem, which is more commonly known as 'Shevaroy Bauxite Deposit'. The Shevaroy hills are situated about 10 km north of Salem town, attain an elevation of about 5000 feet above M.S.L. and lie in between N11°48'17" to 11°50'31" and E78°14'03" to 78°72'53". The bauxites are mainly confined to six hill tops which were residually derived from the underlying charnockites. The bauxitic profile is demarcated as unaltered parent rock - altered parent rock - lithomargic clay - aluminous clay - laterite - aluminous laterite and ferruginous cap. At places, it is covered by very thin soil cover. Bauxite occurs as lenticular deposit which varies in thickness and quality from place to place.

X-ray studies and microscopic investigations revealed that gibbsite is the predominant constituent of the bauxites, even in the iron-rich samples. Goethite, kaolinite, hematite, limonite, anatase are other important minerals of bauxites in order of abundance. For the first time, a new mineral 'Variscite-Ferrian' ($AlFe(PO_4)_2.H_2O$) has been noticed in these bauxites.

The major oxide geochemistry of bauxite profile indicates the gradational and progressive chemical changes i.e. enrichment of Al_2O_3, Fe_2O_3 and TiO_2 with the depletion of SiO_2 content from charnockite to the top-most lateritic zone. Al_2O_3 maintains antipathetic relationship with Fe_2O_3 and SiO_2. The relationship in between Al_2O_3-Fe_2O_3 and TiO_2

with SiO_2 is also found to be negative throughout the profile. Only sympathetic relationship exists in between Al_2O_3-TiO_2 and Al_2O_3-LOI. The antipathetic relationship is indicative of the different physico-chemical environment prevalent in the various zones of the profile, wherein they remove/concentrate each other in their favourable environment.

Alkalies and alkaline earths were mainly depleted and their concentration only in traces was noticed. Only in a few samples in which the mineral Variscite-ferrian is present the phosphate content reaches up to 28%.

The geochemistry of trace metals reveal that Zr, V, Ga and Cr are enriched in most parts of the profile.

Pb, Zn, Cu, Ni, Mn, etc. show slight enrichment only in the lithomargic zone because of its adsorption property.

Co, Ba and Sr show a marked depletion upwards while Pb, Zn, Sn, Ge, Be, etc. do not show any definite pattern of either depletion or concentration during the process of bauxitization.

Cr, Ga, V, Zr show a sympathetic relationship with Al_2O_3 and Fe_2O_3, but particularly vanadium shows close affinity with Fe_2O_3.

Inter-relative studies of major and trace elements reveal sympathetic relationship between Ca-Ga, V-Zr, V-Fe, Ti-Ga, Cr-Fe, V-Ga, while antipathetic and random relation is noticed in between Al and Mn, Fe and Mn, in various zones of the bauxitic profile.

It is considered that Eh and pH plays an effective role in maintaining the relationship between different elements within the same zone of the profile.

Study of genesis and bauxitization processes revealed that this bauxite is residually derived from the underlying charnockites, passing through the five weathering stages. In the initial stage desilicification of parent rock minerals takes place, while in second stage, primary minerals are converted into clay minerals (kaolinite).

In the third and fourth stages, the primary minerals get completely replaced by secondary minerals like, gibbsite, goethite, anatase, etc. with the retention of bauxites and laterites. In the fifth stage, migration of various elements, influenced by organic activities and oxidation of iron minerals from goethite to hematite, occurs.

An attempt has also been made to classify these bauxite deposits. A number of factors were taken into account for the classification, viz., chemical composition, origin and mode of occurrence, texture, mineralogy and geological age. Classification based on chemical composition (represented by a triangular diagram with the apices of SiO_2, Al_2O_3 and Fe_2O_3) and extent of lateritization, have been adopted particularly for Shevaroy bauxites. The terms li silicanite, laterite, aluminous laterite (Allite), bauxite, ferruginous bauxite (Ferrite), etc. are coined according to their chemical composition.

Study of the correlatable planation surfaces and presence of trihydrate aluminium mineral (gibbsite) in these bauxites are suggestive of their Pre-Mio-Pliocene (Eocene) age.

Particularly in our country uniqueness of this bauxite deposit could be mentioned by its occurrence at an exceptionally high elevation, because of the tectonic disturbances along the boundary fault, absence of pisolitic and oolitic texture, high SiO_2 and Fe_2O_3 content and non-uniform trend of bauxitization.

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It is to certify that Mr. Mohammed Nasir Khan has completed his research assignment entitled, "Geochemistry and Genesis of the Bauxite Deposit around Yercaud, District Salem, Tamil Nadu"; under my supervision. It is his original contribution which has neither been published nor submitted for any other degree of this or any other university.

Mr. Khan, is therefore, allowed to submit the same in the form of a thesis for the award of the Ph.D. degree of Aligarh Muslim University, Aligarh.

(S.H. ISRAILI) 7. XII. 1984
SUPERVISOR

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(MOHAMMED NASIR KHAN)

CHAPTER - I

INTRODUCTION

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INTRODUCTION

I.1 : GENERAL STATEMENT :

Aluminium is the most important of the non-ferrous metals. Though it is known to be the most abundant element in the earth's crust, its extraction on a commercial scale began only in 1859. In our country bauxite is the only economic ore for the production of aluminium.

The term 'Bauxite' was introduced by P. Berthier (1821) for sediments rich in alumina from the locality 'Less Baux' in France.

In order to become an economic ore of aluminium, bauxite should contain not less than 45% of Al_2O_3, not more than 20% Fe_2O_3 and 3-5% combined silica.

Based on mineralogical and chemical composition of bauxites various nomenclatures, were suggested viz., laterite, aluminous laterites and bauxite according to the percentage of hydrated Al and Fe. Bauxites and laterites are the two coherently associated products of intense sub-aerial rock weathering whose Fe and/or Al content is higher and Si content is lower than in merely Kaolinized parent rocks. They consist predominantly of mineral assemblages of gibbsite, goethite, hematite, kaolinite, etc.

Since the non-ferrous metals play a vital role in the service of mankind, aluminium in particular with its growing demand and unlimited range of application and extensive use in almost every sector of the economy makes it more in demand. It is also in use of energy, steel, transport, communication, rural electrification, housing, house hold appliances, etc. It may therefore be considered as a metal of 20th Century.

As stated by Schellmann (1980) that all the secondary products of chemical weathering whose Al_2O_3 content is in excess of corresponding Fe_2O_3 values and with lower SiO_2 content in comparison to parent rocks, may be regarded as 'Bauxites'. The weathering products therefore rich in Fe_2O_3 over Al_2O_3 are defined as laterites.

The area selected for present research work in Tamil Nadu state, is known as 'Shevaroy Bauxite Deposit' falls in Salem district of the state. It is the only deposit in Tamil Nadu where bauxite is being commercially exploited by the Madras Aluminium Company (MALCO).

Other deposits of this state having limited quantities of bauxites are the Nilgiri, Palni, Kollaimalai, Kodai-Kanal and Ariyur Nadu.

The deposit is of residual type found as cappings over six small hillocks. The Shevaroy hill range bauxite is derived from the charnockites of diverse nature and roughly occupies a tract of 25.74 km in length and 19.31 to 20.92 km in width.

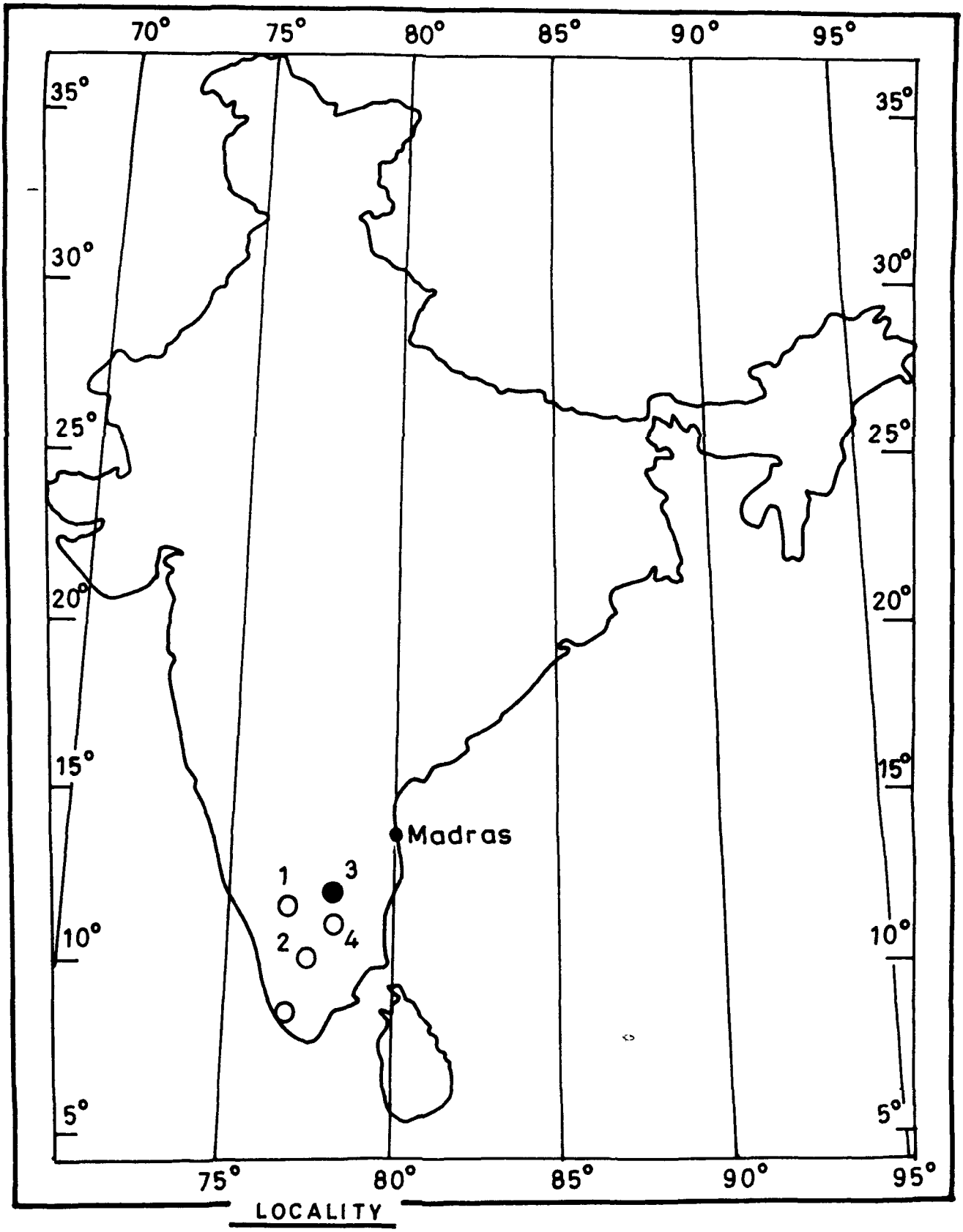


FIG.1 LOCATION MAP OF BAUXITE DEPOSITS IN TAMILNADU STATE WITH SPECIAL REFERENCE TO SHEVAROY BAUXITE DEPOSIT (YERCAUD)

I.2 : LOCATION & COMMUNICATION :

The Shevaroy bauxite deposit is situated about 13 kms North-East from Salem town and 4 kms north of Yercaud and 350 kms South-South-West of Madras. It lies between N11°48'17" to 11°50'31" and E78°14'03" to 78°72'53" and falls in Survey of India Toposheet No. 58 I/1 (Figs. 1 & 2).

The area is accessible from Aligarh to Salem by rail via Madras. For a distance of 30 kms, there is an excellent asphalt road from Salem railway station to Yercaud town, a hill station and one of the most delightful summer resorts in south India at an altitude of about 4500 feet. From this place the hills could be reached by partly metalled and partly non-metalled road.

I.3 : PHYSIOGRAPHY & GEOMORPHOLOGY :

Physiographically, the Shevaroy bauxite occurrences are remarkable for occurring at an unusual height of over 5000 feet above M.S.L. The hills are roughly oval or elliptical in shape (Plate 1, Fig. 1) which are drained on all sides by a net work of streams and the bauxite is present just above the points from where the stream starts flowing downwards. The streams are dendritic in pattern and flow in all directions (Fig. 2). There are some seasonal mountain streams scattered in the entire area

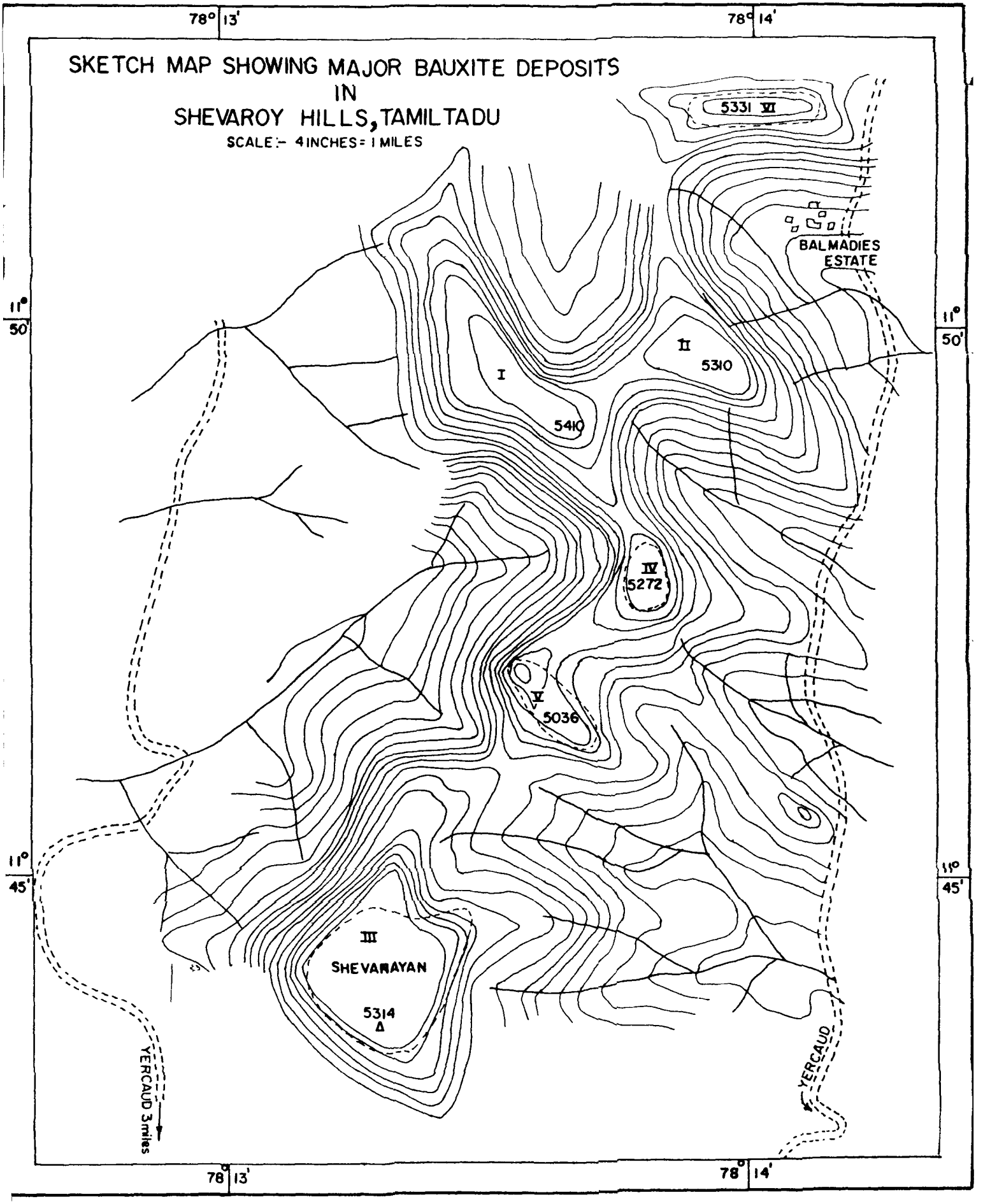

SKETCH MAP SHOWING MAJOR BAUXITE DEPOSITS
IN
SHEVAROY HILLS, TAMILTADU
SCALE :- 4 INCHES = 1 MILES
78° 13'
78° 14'
11° 50'
11° 45'
5331 VI
BALMADIES ESTATE
I
5410
II
5310
IV
5272
V
5036
III
SHEVARAYAN
5314
YERCAUD 3 miles
YERCAUD

FIG. 2

in which water supply is dependent on seasonal rains. The sharp and abrupt difference in elevation between the surrounding plain and the hill is a striking physiographical feature.

The geomorphological features of this region are similar to the entire charnockite terrain as summed up by Radhakrishnan (1968). Geomorphologically, the area is marked with high altitudinal hills and gentle to steep slopes of individual hills. These hills are of pronounced rounded character. The highest peaks are the Sholakaradu (5410 feet) and the Shevarayan(5314 feet).

Lithological and geochemical characters of the bauxites reflect the key role of geomorphology in their formation. Many workers have observed the importance of geomorphology in the resultant end product of residual chemical weathering (Krishnan, 1945; Vaidyanadhan, 1978; Mc Farlane, 1968 & 1980; Subramanian, 1980; Karunakaran, 1980; Pollack, 1980 and Ramam, 1981). Topography and drainage have direct impact on the removal/concentration of certain elements.

I.4 : METEOROLOGICAL DATA :

Being a region of high to moderate elevation, the plateau portion of hills enjoys an equable climate, a uniformly lower range of temperature, which ranges in between 15^{o}C in the month of December-January to 25^{o}C

during May. The maximum temperature in summer months at times goes beyond 30°C. The average annual rainfall on these hill regions is about 1500 mm. Average to heavy rainfall months are from June to September.

Humidity ranges from 70% in the month of March to 90% in December. The pleasant climate favours the luxuriant growth of vegetation in this area.

I.5 : FAUNA & FLORA :

Eucalyptus globulus, Artocarpus integrifolia (Jack), Mangifera indica (Mango), Orange, Pineapples and Coffee herbs are the main floras. Lizards and monkeys are main animals of this area. Previously, this forested area was saturated with wild animals, but later on due to blasting and other mining activities they shifted their place.

I.6 : PREVIOUS WORK (HISTORY OF THE DEPOSIT) :

The Shevaroy bauxite deposit was first investigated by Dickins, a coffee planter at Yercaud, who wanted to use ochreous looking material on the Shevaroy peak for paints. On analysis, it was found to contain an appreciable amount of alumina. It was therefore termed as aluminous laterite or bauxite by Fox (1940). Geological Survey of India investigated the deposit

in detail and studied the quality and quantity of the bauxite.

In the middle of 20th Century, Dr. Sabot of the Pichiney Company, Paris, after examining this bauxite deposit suggested that further prospecting is necessary to give a definite view on the suitability of the deposit.

Accordingly, the state Geology Department carried out detailed prospecting work for bauxite, and collected 600 samples from 30 trial pits for analytical work.

Krishnan (1942) gave a detailed account of the geology of the Shevaroy hills and the nature of occurrence of bauxite deposits along with a rough estimation of reserves. He also advocated the residual origin of bauxite under tropical or subtropical conditions. Krishnaswamy (1958) studied the nature, mode of occurrence and characteristics of these bauxite deposits. With the help of drilling on each hill, he prepared the complete bauxite profiles. Krishna Rao et al. (1974) and Krishna Rao & Borreswara Rao (1976) studied the mineralogy, mode of occurrence, trend of mineral weathering of these bauxite deposits in detail. Mineralogically, they classified the country rock as mafic, intermediate and garnetiferous.

Subramanian and Mani (1980) described the genetic and geomorphic aspects of laterites on high and low landforms and studied the inter-relationship between the planation history of the area and lateritization and correlated the planation surfaces of all the four

(the Nilgiri, the Palni, the Shevaroy and the Kollaimalai hills) hill ranges.

Practically no work has yet been done on the geochemistry or more accurately trace element geochemistry of bauxite deposit in Shevaroy hills. This would be the first attempt to study the geochemistry of bauxites with special reference to trace elements distribution in bauxites and associated rocks in the area. The present work is primarily concerned with a comparative study among the major, minor and trace elements of bauxites and their concentration and removal with the change in physico-chemical environment during the process of bauxitization/ lateritization.

I.7 : AIMS & SCOPE :

Laterites and bauxites are of special interest for their study because they are abundant in many parts of the world and our country has also large and extensive deposits. As stated earlier, bauxite is the only ore of aluminium, chiefly used in the extraction of aluminium metal. Being a good conductor of heat and electricity, it has almost replaced copper and other metals in the electrical and mechanical sectors. It is also used as abrassive and in making the large number of chemicals. Valeton (1972) has nicely illustrated the aluminium

consumption of any country as the so-called index of industrialization. She also regarded this metal as the 20th Century metal. It is therefore imperative to have a deep and systematic study of various bauxite deposits with special reference to the factors responsible for the process of bauxitization. The present investigations are therefore being carried out with the following objectives in view :-

1. To understand the governing factors involved during the process of bauxitization in the study area.
2. To understand the twin processes of residual and chemical weathering.
3. To understand the various stages involved in the process of bauxitization.
4. To study the mineralogy and chemistry of the various rock units in order to understand the genesis of the various minerals present in the bauxite and to assess the quality of the deposit.
5. To understand the geochemical behaviour, distribution and dispersion of the major and trace elements associated with bauxites.
6. To understand the geochemical behaviour of alkali metals like, Na and K in relation to pH.

7. Classification of bauxitic profile and its application in exploration and exploitation of both the bauxitic and lateritic deposits that are consiguous in their mode of origin.

I.8 : STATUS OF BAUXITE IN INDIA :

India is very fortunate in having vast deposits of bauxites. Though all investigated deposits are not yet of economic importance because of low alumina content and other impurities. Yet with the technological achievements, the days are not far off when even low grade deposits will also be in demand.

At present total estimated reserves of Indian bauxites are more than 2400 million tonnes as compared to the earlier meagre tonnage of 250 million tonnes. Major production of the bauxite comes from 10 states namely, Bihar, Andhra Pradesh, Orissa, Maharashtra, Madhya Pradesh, Gujarat, Tamil Nadu, Karnataka, Uttar Pradesh and Goa. Orissa and Andhra Pradesh together constitute a very extensive and large deposit popularly known as 'East Coast Bauxite' which was discovered few decades before by S. Narayanaswamy of Geological Survey of India. This high grade bauxite deposit remained unnoticed till the end of the last decade on account of deceptive lateritic appearance. Discovery of this deposit

reversed the rank and status of India in the list of bauxite producing countries in the world.

Out of the total estimated reserves East coast bauxite deposits contributed more than 1800 million tonnes in which Orissa and Andhra Pradesh now occupy the first and second place respectively in the list of bauxite producing states in the country.

In Tamil Nadu where present investigations have been carried out, contains a total of 8.18 million tonnes of bauxites, which is a negligible contribution to the total reserves of the country. Important deposits are located at Shevaroy, Kollaimalai, Palni and Nilgiri hills.

The importance of bauxite as mentioned earlier and further study of consumption data of bauxite in India reveal that most of the bauxite goes for alumina making and hence for aluminium.

As the aluminium has unlimited range of applications, therefore its perspective for growth in India is quite bright. According to Ganpati (1983) the per capita consumption of aluminium in India is 0.5 kg as compared to the world average of 5.0 kg. With the large scale industrialization programme envisaged, the per capita consumption of non-ferrous metals in the country could reasonably be expected to register an appreciable growth in coming years.

I.8.1 : CONSUMPTION, DEMAND & PRODUCTION :

Consumption of aluminium in 1981-82, was about 2,31,200 tonnes as compared to 1,75,000 tonnes in 1970-71, thus registering an increase of 32%.

Demand satisfaction by indigenous production in 1981-82 for aluminium was about 90% which was much higher than other non-ferrous metals. Even this little gap between demand and indigenous supply has been and continuously is being met by imports, resulting in appreciable expenditure of foreign exchange.

Although in the modern world, with advanced technology, it is almost impossible to exactly forecast the demand over a long period, yet a demand forecast to the extent possible is essential for planning the orderly growth in the capital intensive non-ferrous sectors, especially in the capital scarce developing economy of India.

Working group constituted in connection with the formulation of the VIth Five Year Plan, had worked out the aluminium demand of 4,96,000 tonnes during the current year (1984-85) and 8,45,000 tonnes by 1989-90." However, the trend of consumption during the past two years has been well below the demand growth rate estimated by the working group. One of the main reason for the recession in the demand has been the drop in

off-take of the electrical sector which accounts for about 60% aluminium consumed in the country.

Government has not recognised that optimisation of the results from investments made in this industry could be possible only if power in required quantities is assured to them. Bharat Aluminium Company (BALCO), for example, has been languishing and making heavy losses due to short supply of power while it should make handsome profits. An expenditure of over Rs. 300 crores in hard currency on metal imports could have been avoided only if required quantum of power had been supplied to BALCO. Although a large captive thermal power plant of 270 MW has now been sanctioned for BALCO and hence products of aluminium could be enhanced substantially.

As it is well known that any plan for the production of metal will have to be primarily based on the availability of ore resources Primary emphasis has therefore to be given on the exploitation of ore resources. Fortunately our country is endowed with abundant resources of bauxites. A comparative statement of the aluminium resources in India before independence and as in 1983, is given below in order to bring out the tremendous progress made in this direction after independence.

Resources position before independence	Resources position as on 1.1.1983
250 million tonnes	2500 million tonnes

As observed, the resource position of bauxite is very comfortable and offers potential for large growth of aluminium. As compared to other non-ferrous metals (Pb - Zn & Cu), one of the advantage in the exploration and exploitation of bauxite deposits is that they are not concealed and therefore are easy to be located. Production and target data for the aluminium as furnished by the working group constituted by Planning Commission for the purpose is given in Table-I.

Table-I : Production and Target Data for the Aluminium are furnished by the Working Group on Planning (Journal of Mines Metals & Fuels, January, 1983, Vol. XXXI, No. 1).

Aluminium	At the end of IV Plan production 1973-74	At the end of V Plan production 1979-80	At the end of VI Plan target 1984-85	Working group report projection for the end of VII Plan 1989-90
	1,47,900 tonnes	1,92,000 tonnes	3,00,000 tonnes	5,70,000 tonnes

Large scale development of alumina and aluminium is quite significant in the Indian context. With its abundant bauxite resources, India can install major industries. The present strategy for development of aluminium in the country is to establish such capacities for the metal that will meet domestic demands and to produce additional quantities of alumina so that this added product could be exported to earn foreign exchange.

The Orissa Aluminium Project, which will produce 8,00,000 tonnes of alumina per annum, will use, 4,25,000 tonnes for conversion to 2,18,000 tonnes of aluminium, per annum, leaving an exportable surplus of 3,75,000 tonnes of alumina. A feasibility report for the establishment of an alumina project of 6,00,000 tonnes to 8,00,000 tonnes per annum capacity based on the East coast bauxite deposits in Andhra Pradesh has been prepared in collaboration with U.S.S.R. and modalities on implementing the project are currently under discussion with that country. The Andhra Project could form the nucleus for a full-fledged aluminium industry in the second phase for which feasibility studies will be undertaker as soon as a satisfactory solution to the question of implementing the project is reached. A feasibility study has also been completed for a 3,00,000 tonnes per annum alumina plant based on the bauxite deposits of Kutch in Gujarat state. If these projects materialise in response to external demands for alumina, India would become a major producer

and exporter of alumina to the tune of over one million tonne per annum with the potential for capacity to rapidly increase to much higher magnitudes. Commissioning of the Orissa Aluminium Complex by the middle of 7th Plan will help to reach a demand satisfaction level for aluminium over 70%.

As described earlier that the demand for aluminium will grow steadily in future, necessary measures therefore will have to be taken to conserve the deposits, because these are non-renewable resources and once extracted are lost for ever. It is essential that concerted efforts are made for utilization of low grade and complex ores also. Another important aspect from the conservation angle is the recovery of by-products of minor but valuable metals present in small quantities, such as gallium, nickel, titanium, cobalt, etc.

As India grows into a large aluminium user as well as producer of metal, it will be necessary to give adequate attention to research and development needs of the indsutry. The rapid development of the aluminium industry envisaged calls for the timely establishment of a national level research, development and design centre for aluminium in India. The demand for technical and research personnels would increase, thus attention must be paid to prepare technical and research personnels with sound and uptodate knowledge in the subject for better exploitation of the deposit.

CHAPTER - II

LABORATORY METHODS AND TECHNIQUES

CHAPTER - II

LABORATORY METHODS & TECHNIQUES

II.1 : GENERAL STATEMENT :

Instrumental analysis plays a key role in understanding the grade or quality of bauxite deposits, their economic utility and trend of enrichment/depletion of various oxides and trace metals, with the advancement of weathering processes. Rapid analytical instruments such as Flame photometer, Spectrograph (Spectrometer), Atomic Absorption Spectrophotometer, etc. are conveniently utilised for the determination of the constituents present in the bauxites which avoid much needed time in routine analytical procedures. X-ray studies are used to detect the exact mineral phases present in the bauxite.

II.2 : METHODS OF STUDY :

The author during his field work collected 300 bauxite and laterite samples from all the six hills, in addition to 50 samples of parent rocks from the study area.

Seventy five bauxite samples collected in a grid pattern, 10 to 15 samples from each hill and about 200 samples collected from the exposed sections to establish the complete profile of bauxite in the different hills. On an average profile section, samples were collected after 5-10 feet interval.

The remaining collected samples form the part of float ore at the base of the plateau. The collection of the samples is generally done where-ever any abrupt variation in colour, texture or other physical attributes are marked. Number of the samples from each hill also depends upon the areal extent and variation in the bauxite ore.

II.3 : LABORATORY METHODS OF STUDY :

II.3.1 : PREPARATION OF THE SAMPLE POWDER :

Fresh bauxite and parent rock samples were selected for making the fine powder. About 25 grams of the sample was crushed to -200 mesh in a mechanical grinder. After coning and quartering about 5 grams of the powder was transferred into polythene packs, which was ready for weighing and making the solution for analytical work.

Samples of bauxites and that of the parent rocks were crushed in the same manner, but digested by using different processes of digestion.

II.4 : SYSTEMATIC ANALYSIS FOR VARIOUS OXIDES & TRACE METALS :

A number of analytical methods were followed to determine the various constituents present in the bauxites and their associated rocks. Analytical work was mainly carried out at the Chemical Laboratory, Geological Survey of India (W.R.), Jaipur (Rajasthan) and partly at the Applied Geochemistry Project, Osmania University, Hyderabad (Andhra Pradesh).

Selection of analytical instruments was done keeping in view of the following factors :-

i. parameters to be determined,

ii. precision and accuracy of the methods to be employed,

iii. nature of the problem or interference and

iv. availability of particular instrument.

The different instruments/equipments used in the analysis of various substances are listed below :-

Name of the Instruments/ Techniques	Parameters Determined
1. Complexometric titration with EDTA and spectrophotometer	SiO_2, Al_2O_3, Fe_2O_3, P_2O_5 from hydrofluorized solution
2. Colorimeter, colorimetrically with H_2O	TiO_2
3. Flame photometer	Alkali metals
4. Atomic Absorption Spectrophotmeter (303 - Perkin-Elmer)	Li, Mn, Cu, Pb, Zn, Ni and Co
5. Spectrograph	Ba, Sr, Sn, Mo, Cr, In, Ge, Be, Zr, V, Y, Ga

II.5 : METHOD OF X-RAY STUDIES :

X-ray studies were used to analyse the samples of bauxite and laterites and few of the parent rocks,

collected from different parts of the Shevaroy hills. In order to bring out the exact mineralogical and chemical composition, about 27 samples were subjected to X-ray diffraction method. Each sample was powdered to -200 mesh, care was taken during the powdering because vigorous grinding may result in destruction of crystal structure and may cause variation in d-values. Zussman (1977) pleaded volatile medium like 'acetone' for the same grinding.

X-ray studies were carried out in Applied Geochemistry Project, Osmania University, Hyderabad (Andhra Pradesh) by using Guinier camera and X-ray generator unit filled with copper target. Each time three samples were kept for study and exposed for about 3 hours at 35 KV and 25 milli-amperes current. Normally mineral concentration down to 5% can still be detected. 1 cm diffracted line on the X-ray film equals to the ten degrees of 4θ values. The observed values are compared with the inorganic index of the powder diffraction file (1972), joint commission on powder diffraction standards (pennsylvania, JCPDS).

During the study of films, minimum at least 3 strongest lines should give better agreement with those of calculated 'd' values. During the process of

development, variation in standard conditions may cause shrinkage in the film and hence may create slight variation in the observed values as compared to the calculated values. The film used in X-ray studies is double coated 35 mm film and exposed film was subjected to normal film developing process.

II.5.1 : THEORY OF THE X-RAY STUDIES :

X-rays follow the general characteristic of light rays i.e. reflection, refraction etc.

Bragg on the basis of reflection property of X-rays found that diffracted rays emerging through solids are governed by the following equation :-

$$n\lambda = 2d \sin \theta \quad \text{(Bragg's equation)}$$

where n stands for integer = wave-length of X-ray

d stands for integer = interplanar spacing

θ stands for integer = Bragg's angle

It follows that at particular angle of θ the 'd' values for a particular mineral is definite since every mineral possesses its own crystallographic

arrangement of atom. Detailed work on X-ray studies have been carried out by Burger (1942, 1964), Zussman (1970, 1977). From the study of X-ray films (strips) it was evident that the intensity and strongness of the lines are directly proportional to the concentration of the minerals.

The obtained results are presented in Tables-III & IV.

CHAPTER - III

GEOLOGY, STRATIGRAPHY AND NATURE OF BAUXITIC PROFILE

CHAPTER - III

GEOLOGY, STRATIGRAPHY & NATURE OF BAUXITIC PROFILE

III.1 : GEOLOGICAL & REGIONAL SET-UP OF THE AREA :

A detailed knowledge of the regional set-up is important, because it can reveal whether the variations in altitude are attributable to original lithologically controlled variations, earth movements or differential in post incision cutting (Mc Farlane, 1974; Ramam, 1978 b).

The study area of Shevaroy hills in Salem district is composed mainly of charnockites, belonging to the high grade granulite facies and maintain general NE-SW trend with local irregularities. The Shevaroy hill range which forms a compact unit is considered to be an uplifted massif where present position has been attributed to upheavals along the boundary faults (Bladford, 1867) viewed that the present position of these plateaus is due to tectonic disturbances.

Subramaniam and Mani (1979) mentioned that both Shevaroy hills (about 4550 feet) and the Kollamalai hills (about 3800 feet) are parts of Eastern Ghats. The regional

foliation strike of charnockite rocks is NE-SW and dip steeply towards south-east (Krishnan, 1942). These rocks characteristically display sheet and foliation jointing, besides banding and gneissosity along the road from Salem to Yercaud, thereby indicating that Shevaroy hills were also affected by tectonic changes.

Srinivasan (1974) from photo-interpretation studies, viewed that the attainment of the present elevation of the Shevaroy hills is due to faulting and block movement.

Gopal Rao (1966) mapped the area of Salem district on the scale of 1 : 63,360. Charnockites and leptynites are the common country rocks, which are foliated, having the strike between NNE-SSW and NE-SW with dip of 45^{o} to 75^{o} in easterly direction. Two sets of joints are noted, one set being parallel to the strike and the other in a WNE-ESE or nearly east-west direction. The later set is more prominent than the former.

III.2 : STRATIGRAPHICAL SEQUENCE :

In the area under study, the stratigraphic sequence around the Shevaroy hills as proposed by

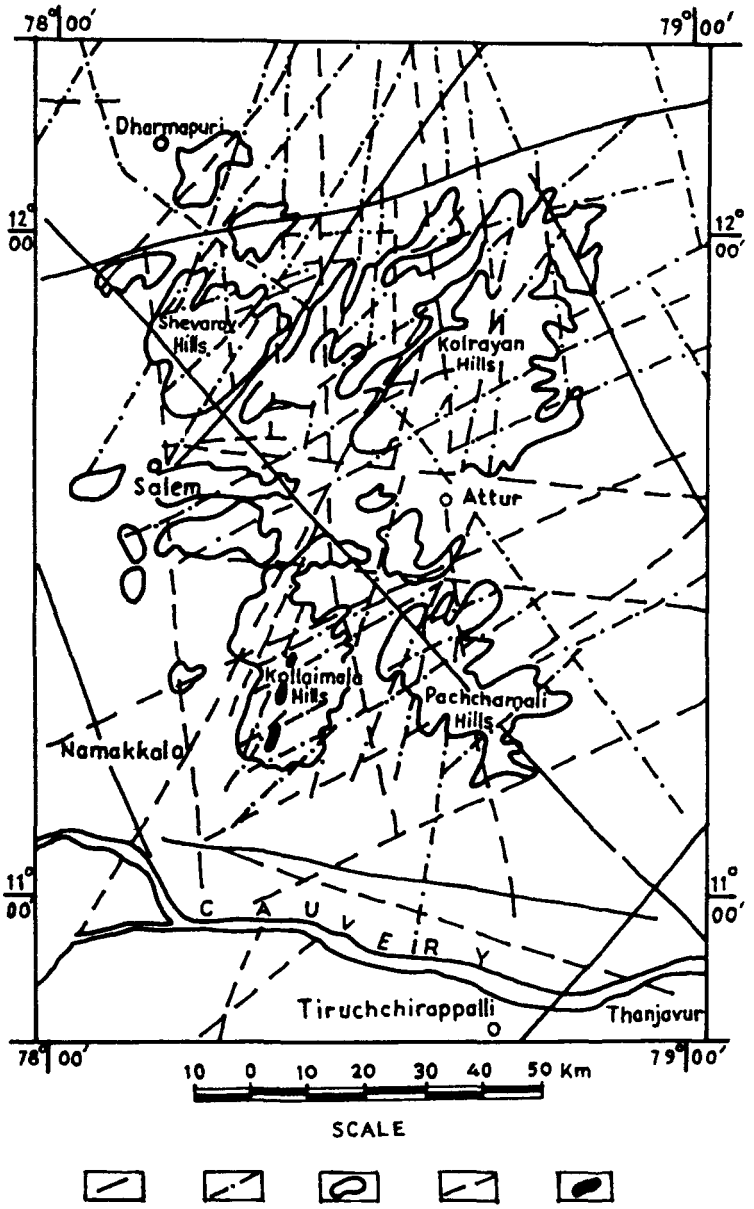
Gopal Rao (1966) and modified by the author is given as follows :-

TABLE - II : Stratigraphic sequence around Shevaroy Hills.

AGE		LITHOUNITS
Recent and Sub-recent		Soil cover Laterite-bauxite
Archeans	Charnockite Suite	Gondite Leptynite Charnockite Pyroxinite

Major portion of the area and Shevaroy hills in particular is composed of charnockite suite of rocks.

Narayanaswamy (1971, 1974-75) proposed that the charnockite-khondalite belts of the southern and eastern parts of the peninsular shield constitute distinct and oldest rock units of Archean age, for which he subsequently coined the name Nilgiri/Eastern



1 Mega Lineament. 2 Minor Lineament. 3. Outline of Hills.
4. Intermediate Lineament 5. Areas of Bauxite occurrence

FIG. 4. MAP ILLUSTRATING LINEAMENTS ACROSS SHEVAROY - KOLLAIMALAI HILLS (Based on Landsat imagery interpretation)

(After Subramanian and Mani, 1979)

Ghats group (Gopala Krishnan, et al., 1975) stated that charnockite group of rocks show a poly-deformational nature.

Sugavanam et al. (1974) have established five periods of folding and deformation in the charnockite group of rocks. In Madras area, two periods of folding are recognized by Subramanian (1959) and Merh (1962) and confirmed by Sen, et al. (1970).

Lineaments are responsible for the elevation of landform (Subramaniam and Mani, 1979). They presented a map illustrating the various phases of deformation and lineaments across Shevaroy-Kollaimalai hills (based on landsat imagery interpretation) (Fig. 4). The lesser frequency of lineaments in some parts is obviously the reason for better preservation of plateau landforms and the laterite cappings are the characteristics of them. They also traced NE-SW and NNE-SSW lineaments on the Shevaroy hills, where bauxite cappings are confined to high landforms and are in between the lineaments.

III.3 : DESCRIPTION OF THE DEPOSITS

According to Krishnan (1942), the Shevaroy bauxite deposits have been numbered from 1 to 6, as

shown below by Dickins of Yercaud who holds them under a prospecting licence.

HILLS	ELEVATION IN FEET
No. 1 Sholakaradu	5410
No. 2 Sholakaradu	5370
No. 3 Shevarayan	5314
No. 4 Hill SE of No. 1	5274
No. 5 Hill SW of No. 4	5036
No. 6 Hill due N of No. 2	5331

The highest peaks are the Sholakaradu (5410 feet) and the Shevarayan (5314 feet) both in the south-central part of the hills, sitauted at a distance of 5 to 8 kms, north of the pleasant hill station of Yercaud ($11^{o}46'30"$: $78^{o}12'30"$). Shevaroy bauxite localities around Yercaud in the Salem district have been shown in Figures 1 & 5.

As shown in the figure 1, Hill Nos. 2, 3, 4, and 5 lie on one line the other two lie west of this line.

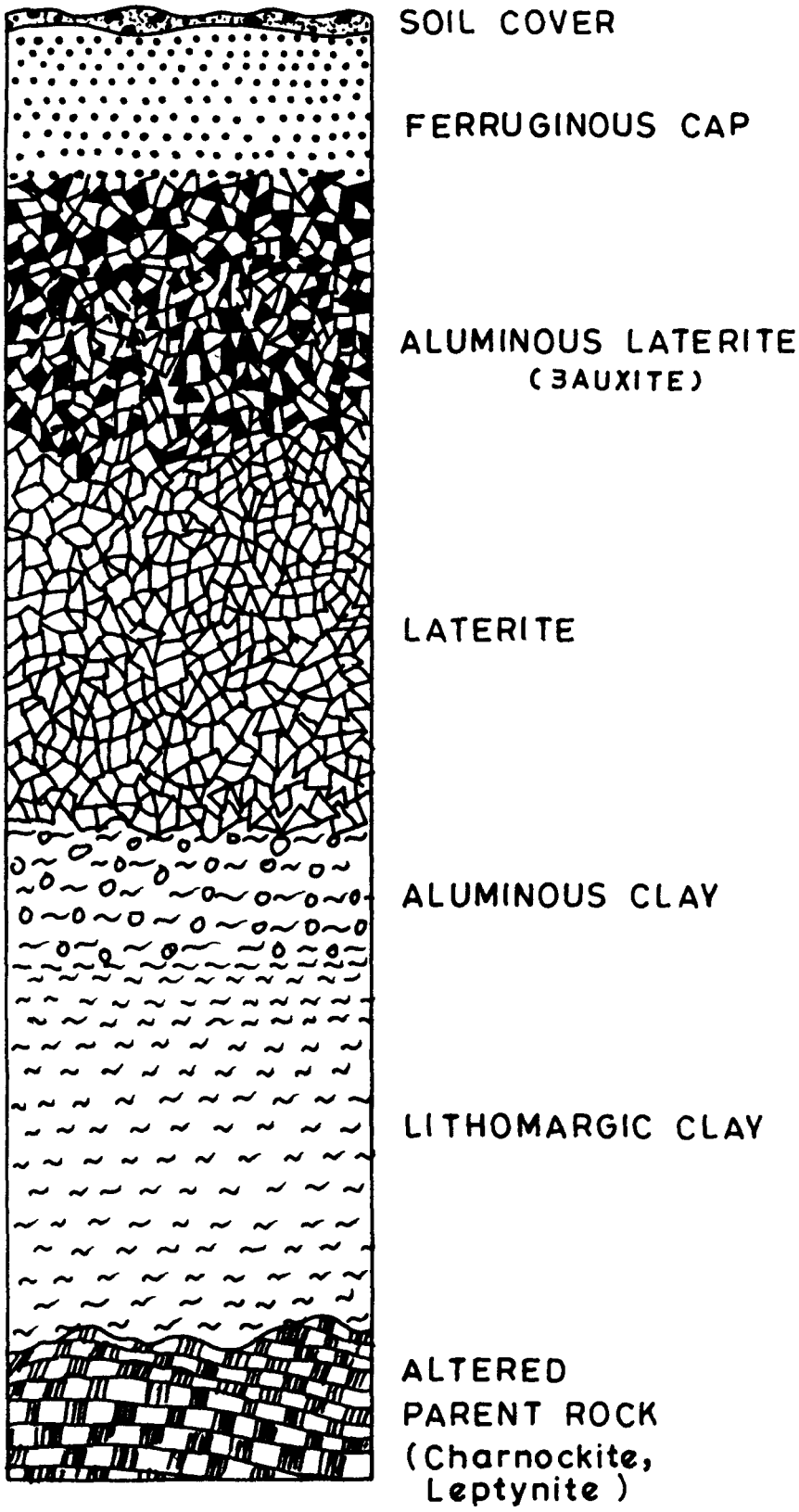


FIG. 3 GENERALIZED VERTICAL SECTION OF BAUXITE AND LATERITE CAPPING IN SHEVAROY HILLS (YERCAUD).

Krishnaswamy (1958) pointed out that the occurrences of bauxite and aluminous-laterite on the Shevaroy hills are confined to the top of six hills with an average altitude (5,000 ft.) that lie on two en-echelon zones trending in an approximately NE-SW direction.

Trend of these hills appears to be following the general strike of the rocks and the lateritization is also seen to follow the general strike and dip of the parent rocks.

A general sequence of the Shevaroy bauxite profile is as follows (Fig. 3) :-

- Very thin soil cover
- Ferruginous-bauxitic zone
- Aluminous-lateritic zone
- Lateritic zone
- Aluminous-clay zone
- Lithomargic-clay zone
- Altered charnockite
- Unaltered charnockite

As observed during the field studies, unequal thickness of the ore body on the Shevaroy hills is

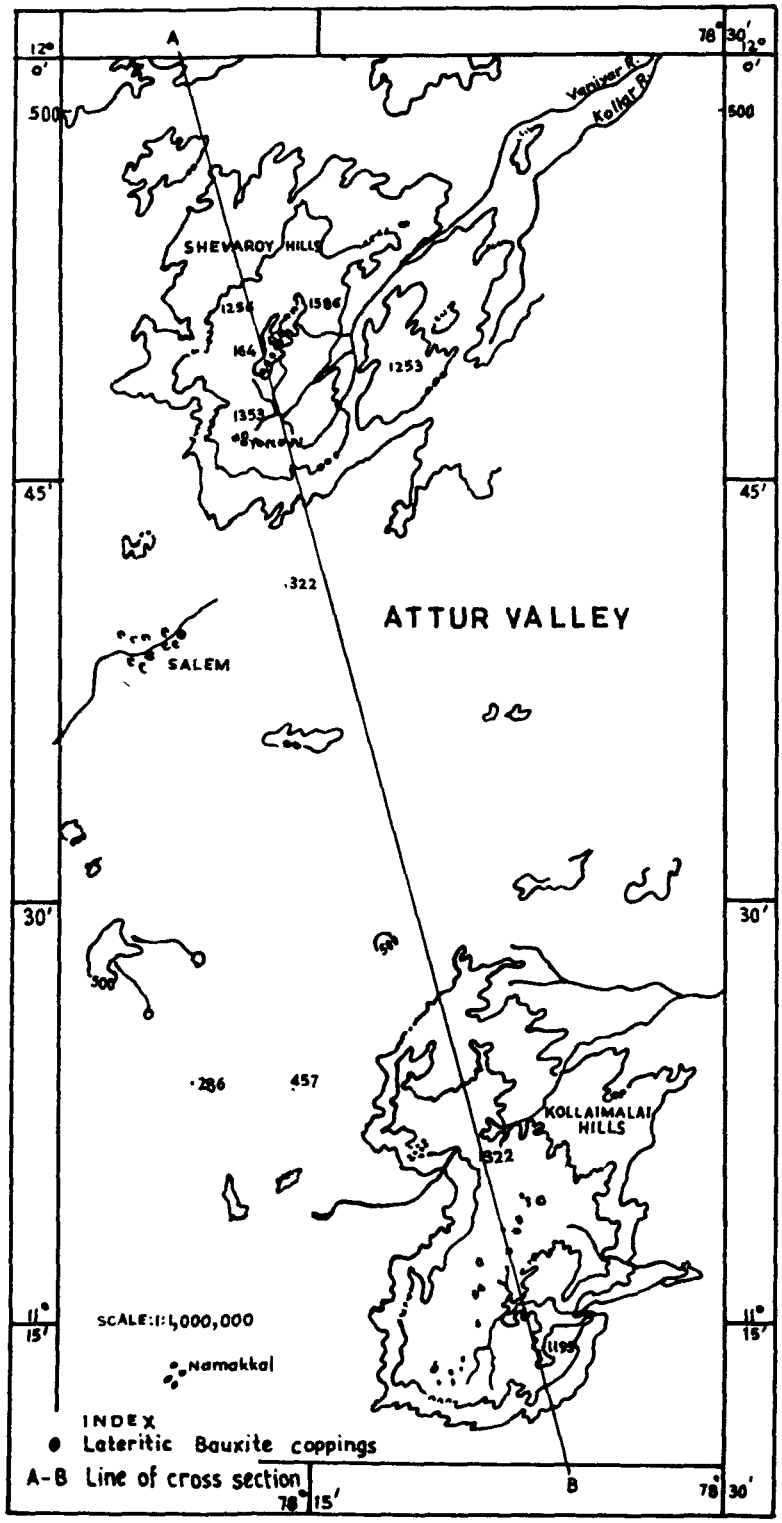


FIG.5 SHEVAROY BAUXITE LOCATION AROUND YERCAUD, DISTRICT SALEM (TAMILNADU)

noticed which support the view that selective leaching of the original rocks has taken place. The lateritic zone is comparatively thinner towards south-east.

Well rounded topography of the lateritic bearing hills, devoid of vegetation, are the characteristic and note-worthy features of the study area. The primary deposits are usually surrounded by a zone of detrital laterite, derived from them by the process of erosion. At places, this detrital material is found to be recemented. Mode of occurrence of the valley laterites at places suggests that it is not an alteration product of charnockites, but is of detrital origin.

III.3.1 : HILL NO. 1 (SHOLAKARADU) :

It is situated in between latitude $11^{o}48'49"$ and $11^{o}50'05"$ and the longitude $78^{o}13'25"$ and $78^{o}13'40"$ and attains an elevation of 5410 feet above M.S.L. It is the highest peak in the area with a capping of about 12.1 acres of primary bauxite. The top of this hill is exceptionally flat with highest point near the south-eastern end. The ore is mostly confined to the plateau portion. The deposit is somewhat lense shaped in outline, the thickest portion being near the highest point, and

thinning both in east and west direction. Based on the number of prospecting pits by Shevaroy bauxite company and Department of Industries and Commerce of Tamil Nadu, the average thickness of the ore is about 35 feet, except at the extreme margin. This highest peak is not wholly covered by laterite. The primary ore extends over the eastern half of the top portion of the hill, whereas on the western portion, charnockites are exposed. The ore is either compact or porous, brick red or pale yellow in colour. In this hill, bauxite has been found at one or two points at a depth of 60 feet also.

The total reserves of the ore in this hill as calculated by the State Directorate of Geology and Mines is about 0.77 million tonnes. The following sequence could be recognised in the bauxite profile.

Description	Approximate thickness in feet
Dark pink porous lateritic boulders with clayey material, embedded in soil or sub-soil	0-4
Red ferruginous rock with white buff clayey material poor in bauxite	4-6
Dark red or pink rock containing bauxite, mixed with ferruginous rock	6-9

contd.....

Red ferruginous rock with smaller proportion of buff clayey rock, poor in bauxite content	9-12
Pale pink and brown coloured rock containing bauxite admixed with ferruginous and clayey material	12-15
Brown coloured rock rich in bauxite content with buff coloured clayey bauxite	15-19
Red ferruginous rock with nearly equal proportion of buff clayey bauxite and pale pink coloured bauxite	19-24
Predominantly pale yellow lithomargic clay with little amount of pale pink clayey bauxite	24-28
Pale yellow lithomargic clay with subordinate amount of white lithomargic clay	28-30
Pale brown rock rich in bauxite with smaller amount of pale yellow and white clay	30-34
Lithomargic clay (kaolinite)	34-36
Parent rock	36

Mining work for the bauxite exploitation is totally manual and transportation to the Mettur Aluminium Plant is by means of trucks.

The bauxite of this hill on analyses has been found to have the following average chemical composition.

Major Oxides

%	Al_2O_3	Fe_2O_3	SiO_2	P_2O_5	TiO_2
	54.33	11.46	2.52	0.16	0.64
%	LOI	CaO	MgO	Na_2O	K_2O
	30.39	nil	0.01	0.07	0.01

III.3.3 : HILL NO. 2 (SHOLAKARADU) :

It lies in between latitude $11^{o}49'25"$ and $11^{o}50'00"$ and longitude $78^{o}13'47"$ and $78^{o}13'58"$, and attains an elevation of 53,70 feet above M.S.L. The Hill Nos. 1 and 2 are separated by a valley in which some reefs of charnockites are well observed. This is well rounded or nearly circular, flat topped plateau, sloping very gently from the centre to the sides. This hill is considered as the best part of the deposit. Primary bauxite covers about 26.1 acres. Charnockites are exposed along the western margin of the plateau. It is very much clear from the studies of pit section carried out by 'MALCO', Tamil Nadu Department of Industries and Commerce and Geological Survey of India

that the bauxite ore is fairly compact, either brick red or of pale yellow in colour. At certain places, thick hard hematitic bands are met with which give rise to high iron percentage in these bauxites at certain places. The average thickness of bauxite on the plateau portion is about 30 feet which at margins of the plateau comes down to about 18 feet. The calculated total reserves are about 1.63 million tonnes. Towards the base of the plateau, particularly on the north-eastern flanks, there are pockets of primary bauxite. Exploitation of the ore is totally done manually and transportation of the mined ore is possible only through trucks.

On the north-eastern side of this hill, a typical exposure of bauxite is seen, which is somewhat unique in colour, hard and compact, the upper surface of which show effect of solution. X-ray studies reveal that this unique sample of bauxite mainly contain quartz and variscite-ferrian (a new find in these laterites).

On this hill, good quality of bauxite is met which is siliceous in nature and contains free quartz. Iron fillings of black or dark red colour in the laterite samples is frequently observed. The generalized sequence of bauxite profile is given as follows :-

Description	Approximate thickness in feet
Greyish black soil with ferruginous bauxite	0-2
Buff reddish and dark pink coloured lateritic rock poor in bauxite	2-6
Buff and red ferruginous rock carrying bauxitic material	6-10
Pale pinkish coloured bauxite bearing rock admixed with small amount of quartzitic material	10-13
Buff clayey bauxite with smaller proportion of porous dark pink coloured rock rich in bauxite content	13-19
Porous pale-pinkish rock carrying small amount of bauxite and clay	19-23
Porous pale-pinkish coloured rock mixed with dark coloured bauxite rock	23-26
Dark grey, pinkish and white coloured lithomargic clay admixed with quartzitic material	26-29
Parent rock	29

The bauxites on analysis gave the following average chemical composition :-

Major Oxides

%	Al_2O_3	Fe_2O_3	SiO_2	P_2O_5	TiO_2
	45.64	19.91	5.79	0.22	1.8

%	LOI	CaO	MgO	Na_2O	K_2O
	26.27	nil	0.02	0.02	0.01

III.3.3 : HILL NO. 3 (SHEVARAYAN) :

It is situated between latitude $11^{\circ}43'46"$ and $11^{\circ}44'50"$ and longitude $78^{\circ}13'04"$ and $78^{\circ}13'24"$ and is the southern most deposit with a large level plateau portion measuring about 26.90 acres in areal extent, although the primary bauxites altogether cover an area of about 37.5 acres. It attains an elevation of 5314 feet above M.S.L.

Scarp faces and various pits and boreholes made by earlier investigators helped in understanding the nature and quality of the ore. In general, the ore of this hill, is of heterogeneous character. The quality of ore varies from pit to pit and it is very much irregular. On one third of the northern plateau portion,

bauxite is thin and of poor quality. However, fairly thick and good bauxite occurs on the eastern and south-western margins of the plateau. It reveals that the variation in quality occurs across the general strike and dip directions of the host rock. On the eastern margin and on the slopes, the ore extends in some places, to as much as 50 feet deep but very often thick lenses of hard hematitic material intercalate with bauxite. Further free silica is found in fairly large proportion in the associated bauxites. In this hill, the average thickness of primary bauxite is about 22 feet, and the total reserves are about 2.13 million tonnes. Besides,it, there is float ore, covering an area of 5.8 acres. On the eastern side, the bauxite is embedded in ferruginous material. At some places, the cherty hematitic material approaches an iron ore, which does not contain any gibbsitic mineral. The aluminous laterite or bauxitic material is generally yellowish or cream in colour which is earthy and rarely hard in appearance.

Sequence of bauxite profile in this hill is as follows :-

Description	Approximate thickness in feet
Brownish, greyish and yellow soil with lateritic boulders embedded in it	0-2
Brownish, reddish pseudo-lateritic rock with little pinkish and brown bauxite	2-8
Brown ferruginous pseduo-lateritic with more pinkish brown bauxite	8-12
Pinkish and buff clayey bauxite	12-14
Pink white lithomargic clay with very little bauxite and ferruginous material	14-18
Dark pink clayey bauxite with few lumps of bauxite and admixed clay	18-20
Pink lithomargic clay	20-22
Parent rock	22

The analyses of bauxite of this hill on the average reveal the following chemical composition :-

Major oxides

%	Al_2O_3	Fe_2O_3	SiO_2	P_2O_5	TiO_2
	49.40	9.27	12.94	0.13	0.82

%	LOI	CaO	MgO	Na_2O	K_2O
	26.33	nil	0.01	0.02	nil

III.3.4 : HILL NO. 4 (SOUTH-EAST OF HILL NO. 1) :

It is small hill, adjacent to Hill No. 1 situated in its SE direction and is separated from it by a valley (Fig. 1). It lies in between latitude $11^{o}47'35"$ and $11^{o}48'05"$ and longitude $78^{o}13'48"$ and $78^{o}13'53"$. The place in between these hills is covered by built up structures of 'MALCO'. This plateau is elliptical in shape. The primary ore covers about 15.9 acres. Examination of the scarp faces and pit sections gives an idea about the ore, which appears to be of medium quality. Charnockites are exposed on the southwest part of the hill. The average thickness of the ore body is about 22 feet. About 0.61 million tonnes of reserves of ore have been calculated by earlier workers. The bauxite profile of this hill is as follows :-

Description	Approximate thickness in feet
Pinkish red ferruginous pseduo-lateritic rock, poor in bauxite	0-3
Red and buff coloured ferruginous bauxite	3-7
Pale pinkish and brown clayey bauxite with boulders of red ferruginous bauxite	7-10

contd.....

Pale yellow coloured fairly rich bauxite	10-14
Brown coloured fairly good bauxite in pink clayey bauxite with red ferruginous partings	14-18
Quite rich bauxite associated with pink clayey bauxite with little quartzitic material	18-21
Rich bauxite bearing pale pinkish clay admixed with little brown clay	21-24
Lithomargic	24
Parent rock	24

On an average the chemical analyses of bauxite of this hill reveal the following chemical composition :-

Major Oxides

%	Al_2O_3	Fe_2O_3	SiO_2	P_2O_5	TiO_2
	48.11	17.32	4.90	0.16	1.62

%	LOI	CaO	MgO	Na_2O	K_2O
	26.91	nil	0.03	0.02	0.01

III.3.5 : HILL NO. 5 (SOUTH-WEST OF HILL NO. 4) :

It is situated between latitude $11^{\circ}46'30"$ and $11^{\circ}47'02"$ and longitude $78^{\circ}13'31"$ and $78^{\circ}13'36"$. Out of the six hills, it is the smallest hill in the area and lies in between hill nos. 4 and 3. It is very low in elevation and attains an elevation of 5036 feet above M.S.L. It contains bauxites of poor quality. Due to the poor quality of the deposit, it has not been opened so far for the purpose of exploitation. In order to assess the quality of the ore, the author collected few samples only from this hill. The sequences of bauxite profile in this hill was found to be as follows :-

Description	Approximate thickness in feet
Brown or pinkish coloured boulders embedded in dark red soil	0-3
Dark pink and buff coloured ferruginous or pseudo-lateritic rock with small admixture of bauxitic material	3-6
Porous bauxitic rock, predominantly buff and pink in colour	6-9
Buff coloured ferruginous bauxite admixed with the grains of relict quartz	9-11

contd.....

Pale pink coloured rock, poor in bauxitic material admixed with lithomargic clay and relict quartz grains	11-13
Lithomargic clay	13-15
Parent rock	15

On analysis the bauxite of this hill give the following chemical composition :-

Major Oxides

%	Al_2O_3	Fe_2O_3	SiO_2	P_2O_5	TiO_2
	50.76	8.52	12.20	0.12	0.54

%	LOI	CaO	MgO	Na_2O	K_2O
	27.10	nil	nil	nil	nil

III.3.6 : HILL NO. 6 (DUE NORTH OF HILL NO. 2) :

It lies in between the longitude $11^{o}51'50"$ and $11^{o}51'53"$ and latitude $78^{o}13'54"$ and $78^{o}14'09"$. It is situated in the northern most part of the study area, and lies due north of Hill No. 2, with an elevation of 5331 feet from M.S.L. Primary bauxite ore covers

an area of about 4.30 acres. The ore appears to be of medium quality. The bauxite ore is earthy and less compact in nature and yellowish brown, and pinkish to reddish brown in colour. Earlier workers calculated the reserves of about 0.15 million tonnes. It is also under exploitation of the ore at present. In this hill, the sequence of bauxite profile is as follows :-

Description	Approximate thickness in feet
Dark pink ferruginous rock with occasional bauxite in red brown soil	0-3
Dark pink and buff ferruginous bauxite	3-6
Pale pinkish and brown bauxitic rock with some clay patches	6-10
Red ferruginous rock with small amounts of richly bauxitic brown rock	10-16
Buff and brownish bauxitic rocks with small amount of red ferruginous rocks and patches of clayey bauxite	16-22
Pinkish brown to buff bauxitic rock with small admixture of clayey bauxite	22-24
White lithomargic clay with little brown clayey bauxite	24-26
Altered parent rock and fresh parent rock	26

The analysis of the bauxites of this hill give the following chemical composition on the average :-

Major Oxides

%	Al_2O_3	Fe_2O_3	SiO_2	P_2O_5	TiO_2
	56.86	8.07	5.14	0.17	1.17

%	LOI	CaO	MgO	Na_2O	K_2O
	31.78	nil	nil	0.03	nil

III.4 : NATURE OF BAUXITIC PROFILE :

The Shevaroy hill bauxites are confined to six hill tops. These peaks are flat topped plateaus (Plate-I, Fig. 1). Present cappings of this area suggests a lithological and geomorphological control in the process of bauxitization. On the Shevaroy hills, bauxites overlies leptynites which are associated with the charnockite suite of rocks (Krishnan, 1942; Krishnaswamy, 1958 and Roy Chowdhury, 1958).

Investigations reveal that the lateritization of parent rocks is neither universal nor uniform, but only confined to certain lenses and zones. Bauxite

occurrences are only patchy and lenticular and they are confined only to certain portions of the plateau on each hill. The bauxite cappins seem to be of uneven thickness on the plateau. They are fairly thick and the thickest at their margins, but thin out along the slopes. At the extreme margins the thickness may not be more than 5-10 feet. While on the thickest portion, it reaches up to 60 feet. The average thickness on the plateau portion may vary from 20-35 feet. The base of the deposits is extremely irregular. The thickness of the deposits tends to be more in the direction of sub-soil and drainage. The remarkable characteristic of the Shevaroy bauxites is that it coccurs parallel to the foliation strike of the country rock. Like those of other tropical region bauxites/laterites, it has also characteristically reddish to yellowish brown colour, composed chiefly of iron, aluminium oxides and hydroxides. The lateritic column is divided into 5 zones, depending on their physical characteristics, such as colour, mineralogy and chemistry. The parent rock is followed by an altered zone to the tune of 6 to 9 feet in which charnockite is completely bleached out and forms lithomargic clay which is approximately 6 to 15 feet thick at places. Above which the dark reddish laterite

is seen. By observing the various scarp faces and pit section it is found that laterite gradually grades into aluminous laterite with thickness ranging in between 3 to 12 feet. It also constitues irregular veins and lenses of bauxite (Plate-III, Fig. 1). At the top of which occurs the ferruginous bauxite, very hard and dark red in colour. In general, bauxites are of earthy type intermixed with silica and are devoid of pisolitic and oolitic structures. Generally, the bauxite is of lateritic type and contains higher proportion or iron with clusters and streaks of crystalline gibbsite in varying proportions.

These six hills show the difference in the level of lateritization which may either be due to several periods of peneplanation accompanied by lateritization or due to post laterite faulting.

Finally, it is inferred that the Shevaroy hills are the parts of the Eastern Ghats and mainly composed of charnockites - a high grade granulite facies rock. In this area, bauxite is mainly confined to six hill tops which attain an elevation in between 5036 and 5410 feet above M.S.L. The bauxite ores occurs as segregations, lenses, reefs and various irregular channels and boulders of various sizes within the

ferruginous cap rocks. Thickness of the bauxite profile is not uniform in all the hills and the ore also vary in grade and mode of occurrence. A typical pisolitic texture of Indian bauxites is totally absent in these bauxites.

CHAPTER - IV

PETRO–MINERALOGY

CHAPTER - IV

PETRO-MINERALOGY

IV.1 : GENERAL STATEMENT :

Petro-mineralogical studies play important role in understanding the series of changes in texture and in mineralogy with the advancement of lateritization, which in turn will be proved helpful in understanding the genetic history of the bauxite residuum.

Representative and selected samples from the Shevaroy hills were examined megascopically in order to understand the texture, influence of weathering, physical and chemical changes, etc. For a comprehensive and detailed study, the selected samples were subjected to X-ray studies and microscopic investigations. Thin sections of various representative samples were prepared for petrographical and mineralogical studies under the microscope. Actual mineralogical constituents of laterites and bauxites are difficult to study because of the predominance of cryptocrystalline and amorphous states and patchy appearance of the minerals associated with fine grained impurities, besides numerous isomorphic replacements between iron and aluminous minerals.

Krishna Rao et al. (1974) observed that in Shevaroy hills, the rocks of charnockitic suite underlying the bauxite deposits consist of quartz, plagioclase, and K-feldspar, ortho and clino-pyroxenes garnet and secondary hornblende.

Detected mineral phases in the bauxite profile include gibbsite, goethite, kaolinite, anatase, quartz and 'Variscite Ferrian' (a new find by the author).

Hematite and boehmite are also observed in minor amount. Each of the bauxite profile is characterised by a definite set of mineral assemblage.

IV.2 : PETRO-MINERALOGY OF THE PARENT ROCKS :

As stated earlier, the Shevaroy hills are mainly composed of rocks belonging to charnockite series.

Subramanian (1960) stated that the charnockite suites comprises rocks initially of igneous origin, modified by metamorphic reconstruction and recrystallization, with concomitant changes in mineralogy such as unmixing of perthites and formation of garnet.

Holland (1900, 1901) for the first time classified the rock types of Shevaroy hills under the group of intermediate charnockites.

Krishna Rao and Borreswara Rao (1976) also classified the rocks of charnockite series, based on

the mineral assemblages as mafic, intermediate and garnetiferous rocks.

In the present study, microscopic and megascopic observations reveal the following mineralogical and petrographic features of the rocks belonging to the charnockite suite.

The charnockites are dark in colour and show almost vitreous lusture. They are medium grained, granular in texture and are characterized by the presence of generally highly pleochroic orthopyroxenes. The charnockites are essentially made up of plagioclase and hypersthene and the later has a definite tendency to occur in clusters. Augite occurs as coarse grained aggregate between other minerals. Accessories include magnetite, ilmenite, apatite and zircon, etc. The plagioclase has well developed twins on the albite law. Optical studies indicate the composition, An_{38-42}, representing sodic-andesite range. Hypersthene occurs as completely anhedral, irregular grains and moderate to strong pleochroism. The observed pleochroism scheme is :-

α = pink, β = greenish yellow, γ = green

Slight stretching of even brittle minerals such as quartz is also observed under the microscope (Plate III, Fig. 2).

Few parent rock samples having the same mineral composition with garnet in addition, are termed as

gondite and leptynite which is also in accordance with the X-ray studies (Table-III, Sr. No. 26), (Plate-VI, Fig. 1).

In hand specimen, gneissosity is also observed showing banding between dark and light coloured minerals.

X-ray studies also reveal the presence of quartz, albite and hypersthene as major minerals in these charnockites. Other accessories could not be detected because of their concentration below the detectable limit (Table-III).

IV.3 : PETRO-MINERALOGY OF BAUXITE PROFILE :

As mentioned earlier the sequence of bauxitic profile include lithomargic-clay zone at the base followed by aluminous-clay zone, lateritic zone, aluminous-lateritic zone and ferruginous-bauxite zone or ferruginous-cap at the top.

Each zone of the profile has differential concentration of the residual minerals. Each unit shows variation in textural and mineralogical (petro-mineralogical) characters, according to the intensity of lateritization.

From the same area (Krishna Rao, et al., 1974) observed that gibbsite and goethite are the ubiquitous and major constituents while boehmite, hematite, kaolinite and quartz are present in minor amount.

The principal ore forming minerals of bauxites include gibbsite, boehmite and diaspore.

In the present investigation, important detected mineral phases of bauxite profile include gibbsite, goethite, kaolinite, hematite, anatase and quartz. 'Variscite Ferrian' is a newly reported mineral from the samples of Hill No. 2 (Table-III, Sr. Nos. 1 & 2).

IV.3.1 : PROPERTIES OF INVESTIGATED MINERALS :

Gibbsite or Hydragillite ($Al_2O_3.3H_2O$) :

Gibbsite is the most important and major mineral constituent of these bauxites. It occurs as crystalline, micro-crystalline, and granular aggregates in the form of cavity fillings, small stringers, veins and vein-like structures. It crystallizes in the monoclinic system.

It is colourless to pale brown in ordinary light, under cross-nicols it shows moderate to weak birefringence. Large tabular crystals generally exhibit polysynthetic twinning with well defined twin-lamellae. On the basis of present observations, it could be inferred that the mineral gibbsite is of two types - micro-crystalline type and granular type (Plate-VI, Fig. 2).

Boehmite ($Al_2O_3.H_2O$) :

X-ray studies indicate the presence of boehmite in minor amount in some bauxite samples in the study area. Under microscope, a few grains which appear to be of boehmite were also detected. They are of rounded in outline and are marked with higher index of refraction.

Kaolinite ($(OH)_8Si_4Al_4O_{10}$) :

It is an important clay mineral, occurs in small veins and cavities. It is pale yellow in colour. Under cross-nicols, it shows weak birefringence. The refractive indices are slightly higher than the balsam (Plate-VII, Fig. 2). It crystallizes in triclinic system. X-ray studies also confirmed the presence of kaolinite in the bauxite profile of the study area.

Goethite ($Fe_2O_3.H_2O$) :

Goethite occurs mainly as interstitial patches. It also occurs as small veins and veinlets and as cavity fillings. At places, it forms fibrous aggregates formed through the aggregation of acicular crystals that show birefringence (Plate-VI, Fig. 2).

Hematite (Fe_2O_3) :

Hematite occurs as small angular fragments to subrounded grains. Generally, hematite has a thin coating of limonite but could be recognised by its metallic lusture and blood red colour in reflected light (Plate-VII, Fig. 2).

Limonite ($2Fe_2O_3.3H_2O$) :

It is pale brown to yellowish brown in colour. It occurs mainly as thin coating or patches on gibbsite.

Anatase (TiO_2) :

The common titanium mineral in these bauxites is anatase. It occurs as small anhedral discrete grains, generally exhibiting high refractive index and birefringence (Plate-VI, Fig. 2). It also occurs within crystalline patches of gibbsite and as inclusions in some gibbsite crystals. The pitted borders and inclusions are the clear indications of its secondary origin.

Variscite-Ferrian ($AlFe(PO_4)_2.H_2O$) :

The new first ever reported mineral from Shevaroy bauxites was noticed during the present investigations in the sample no. 2/8 and 2/9, collected from Hill No. 2.

The hand specimen which contain mineral variscite look like lateritic samples, except some cluster like appearance on the top surface which might have been developed possibly due to the action of phosphate meteoric water. It is crystalline and microcrystalline phosphate of Al and Fe, light green in colour, occurs ordinarily as fine grained masses, nodular, veinlets or as clusters. Under the microscope large number of disseminated rounded grains are observed which show strong pleochroism. Relict quartz grains are also seen (Plate-VIII, Fig. 1).

Chemical analyses indicate the presence of Al_2O_3 (22.94%); Fe_2O_3 (14.79%); SiO_2 (11.07%); P_2O_5 (28.07%) and H_2O (19.86%), on the average.

These samples were also subjected to X-ray studies the result of which agree well with the chemical analyses.

Visual estimation of d-values determined by X-ray studies agreed well with the standard values of JCPDS cards (Plate-IV, Figs. 1, 2, 3 & 4; and Plate-V, Figs. 1, 2, 3, & 4). Minerals identified in the different zones of the bauxite profile on the basis of d(A^o) values are given in the following table.

TABLE - III : Represents the minerals identified in different zones of the bauxite profile on the basis of d(A^{o}) values.

S.No.	Zone	Sample No.	Major Constitutents	Minor Constituents
1	2	3	4	5
1.	Zone-V Ferruginous-Bauxite Zone	2/8	quartz, variscite-ferrian	gibbsite, hematite
2.		2/9	quartz, hematite, variscite-ferrian	kaolinite, gibbsite
3.		2/11	hematite	kaolinite
4.		3/1	hematite, quartz	kaolinite
5.	Zone-IV Aluminous-laterite zone	1/4	gibbsite	goethite
6.		1/10	gibbsite	kaolinite, boehmite
7.		1/13	gibbsite, kaolinite	goethite
8.		1/14	gibbsite	goethite
9.		6/2	gibbsite, goethite	hematite
10.	Zone-III Laterite zone	2/6	gibbsite	anatase, kaolinite
11.		2/13	gibbsite	anatase, kaolinite
12.		3/2	gibbsite	kaolinite, quartz
13.		3/3	gibbsite,goethite	quartz
14.		4/3	gibbsite	ND*

contd.....

1	2	3	4	5
15.		1/12	kaolinite, goethite	ND
16.		2/7	kaolinite	gibbsite
17.	Zone-II Aluminous-clay zone	4/1	gibbsite	quartz
18.		4/16	gibbsite, kaolinite	ND
19.		5/2	gibbsite, quartz	kaolinite
20.		1/9	kaolinite	ND
21.		2/1	kaolinite, quartz	gibbsite, goethite
22.	Zone-I Lithomargic-clay zone	3/6	kaolinite	ND
23.		3/8	kaolinite, gibbsite	quartz
24.		1/15	quartz, albite	ND
25.	Parent Rocks	2/14	labradorite, quartz	ND
26.		3/14	quartz, labradorite	Pyrope (garnet)
27.		4/21	plagioclase, quartz	hypersthene

ND* = Not detected

The observed (predetermined) d(A^{o}) and calculated d(A^{o}) values of the identified minerals are presented in the following tables.

TABLE-IV : Represents the observed (predetermined) d(A^{o}) and calculated d(A^{o}) values of the identified minerals.

(1) Name of the mineral : Hematite

Composition : Fe_2O_3

Intensity	d(A^{o}) observed	JCPDS d(A^{o}) calculated
100	2.696	2.69
60	1.691	1.69
50	2.509	2.51
40	1.838	1.84
40	1.482	1.48
40	1.447	1.45
30	2.202	2.20
30	3.675	3.66

(2) Name of mineral : Quartz

Composition : SiO_2

Intensity	d(A^o) observed	JCPDS d(A^o) calculated
100	3.330	3.34
40	4.257	4.26
20	1.814	1.82
20	1.538	1.54
10	2.450	2.46
10	2.277	2.28
10	1.378	1.38
10	2.123	2.13

(3) Name of mineral : Variscite Ferrian

Composition : $AlFe(PO_4)_2.H_2O$

Intensity	d(A^o) observed	JCPDS d(A^o) calculated
100	3.206	3.21
90	3.184	3.18
80	4.037	4.03
60	3.743	3.75
30	3.135	3.13
30	-	3.63
20	2.527	2.52
20	3.872	3.88

(4) Name of mineral : Gibbsite

Composition : $Al_2O_3.3H_2O$

Intensity	d(A^o) observed	JCPDS d(A^o) calculated
100	4.857	4.85
50	4.392	4.37
30	4.318	4.32
30	2.450	2.45
30	2.384	2.39
20	2.421	2.42
20	2.052	2.04
20	3.312	3.31

(5) Name of mineral : Goethite

Composition : FeO(OH)

Intensity	d(A^o) observed	JCPDS d(A^o) calculated
100	4.178	4.18
30	2.692	2.69
30	2.247	2.45
20	2.187	2.19
20	1.717	1.72
20	2.489	2.49
20	1.562	1.56
10	4.979	4.98

(6) Name of mineral : Kaolinite

Composition : $Al_4Si_4O_{10}(OH)_8$

Intensity	d(A^o) observed	JCPDS d(A^o) calculated
100	7.161	7.17
90	1.487	1.49
90	3.580	3.58
50	1.616	1.62
50	4.329	4.37
30	1.579	1.59
50	4.149	4.19
60	2.520	2.50

(7) Name of mineral : Anatase

Composition : TiO_2

Intensity	d(A^o) observed	JCPDS d(A^o) calculated
100	3.524	3.52
40	1.892	1.89
20	-	2.38
20	-	1.70
20	-	1.67
10	1.480	1.48
10	-	2.43
10	-	2.33

(8) Name of mineral : Albite

Composition : $NaAlSi_3O_8$

Intensity	d(A^o) observed	JCPDS d(A^o) calculated
100	3.206	3.21
90	3.184	3.18
80	4.037	4.03
60	3.743	3.75
30	3.135	3.13
30	-	3.63
20	2.527	2.52
20	3.872	3.88

(9) Name of mineral : Hypersthene

Composition : $(Mg, Fe)SiO_3$

Intensity	d(A^o) observed	JCPDS d(A^o) calculated
100	3.176	3.18
50	2.878	2.88
40	-	2.56
40	-	2.96
30	-	2.51
30	2.480	2.48
30	-	2.72
20	4.035	4.03

IV.4 : DESCRIPTION OF THE VARIOUS ZONES OF THE BAUXITE PROFILE :

IV.4.1 : LITHOMARGIC CLAY ZONE :

In hand specimen, it is reddish brown to yellowish brown or greyish white in colour, porous and heterogeneous in character. At places, it is characterised by fine laminations and inclusions. These inclusions are perhaps due to the concentration of soft, deep red iron oxide (Plate-X, Fig. 1), usually with greasy feal.

It is essentially composed of fine grained micro-crystalline aggregates of clay minerals, in association with varying proportions of goethite and limonite (Plate-VII, Fig. 1). This zone also exhibits the presence of unleached quartz grains. Gibbsite characteristically occurs in the upper part of this zone. X-ray studies indicate the presence of kaolinite and goethite in these samples. Gibbsite occurs in the form of fine crystalline and microcrystalline granular aggregates.

Thin section studies reveal that the ferro-magnesian minerals have been altered to goethite. It occurs within the limonite matrix with gibbsite, and feldspars, part of which has been altered to gibbsite.

IV.4.2 : ALUMINOUS-CLAY ZONE :

This zone also exhibits more or less the same characters except with greater concentration of gibbsite. Kaolinite, gibbsite and goethite are the important minerals of this zone as detected by X-ray studies. Nodules of gibbsite in clay matrix are essentially composed of crystalline gibbsite without any relict texture. At places amorphous silica is noticed as shapeless patches having concentric rims of gibbsite and limonite.

IV.4.3 : LATERITE ZONE :

In this zone, laterite occurs as thick and irregular sheets enclosing discontinuous lenses and patches of bauxites. In general, it consists of ferruginous minerals with minor and variable proportion of gibbsite. It shows a variety of textural features, but cavernous, vesicular and earthy types are most common. Under the microscope, it has been observed that innumerable cavities are filled by clay or secondary iron mineral (limonite) (Plate-IX, Fig. 1). It is typically hard, massive and bouldery and indicate gradual variation in physical characters.

It also shows relict texture, alternate banding of different minerals which simulate the residual weathering of charnockite. X-ray studies indicate the presence of gibbsite, kaolinite and goethite minerals (Table-III).

IV.4.4.: ALUMINOUS-LATERITE OR BAUXITIC ZONE :

Under microscope bauxite display a patchy appearance due to the close association of transluscent to opaque minerals and aggregate shape of gibbsite. Opaque minerals generally occur as narrow, irregular zones, within which occurs kaolinite, limonite (ferruginous material) and grains of gibbsite (Plate-IX, Fig. 2) as interstitial material.

In hand specimen, the bauxites are characterized by the presence of irregularly shaped channels or passage ways, stimulating veins or vein like structures. Gibbsite occurs in veins, interstices and cavities, exhibiting secondary relationship with other constituents.

Petrological and X-ray studies reveal that bauxite is predominantly composed of gibbsite, hematite and with minor amount of goethite, limonite, kaolinite and anatase (Table-III).

IV.4.5 : FERRUGINOUS BAUXITE OR FERRUGINOUS CAP :

It is the top most horizon in the bauxitic profile. Unlike other bauxite deposits, it is devoid of characteristic pisolitic texture.

X-ray studies reveal the presence of hematite, goethite and gibbsite. At few places the crevices are filled up by loose clay or limonite material. Occurrence of gibbsite in veins, interstices and cavities, exhibits secondary relationship with other constituents. Relict quartz grains are also observed under the microscope (Plate-VII, Fig. 2).

A detailed study of petro-mineralogical characters of parent rocks and their trend of weathering in the Shevaroy bauxitic profile reveals that bauxite has been derived from the underlying parent rocks.

Microscopic investigations and X-ray studies further reveal the presence of four principal minerals in the bauxitic profile, viz., gibbsite, kaolinite, goethite and hematite. Anatase, quartz and boehmite occur in traces. Quartz is of residual type. Thin section studies reveal that ferromagnesian minerals are altered to goethite which on oxidation converted into hematite. Feldspar alters into kaolinite. Gibbsite is intermixed with other silica and iron minerals.

From the lower most zone to the top most one of bauxitic profile, the following mineralogical variations were observed.

1. Decrease in kaolinite, quartz and goethite content.
2. Increase in the gibbsite content possibly due to substitution of Al in goethite.
3. Decrease in gibbsite content, because of the replacement of goethite by hematite in the top most layer.

In general, laterite and bauxite show a patchy appearance making it difficult to identify all the minerals due to the presence of crypto-crystalline and crystalline aggregates of minerals closely associated with transluscent to opaque patches of other minerals. Certain characteristic textural and mineralogical features such as presence of certain minerals in veins, cavities, concentration of silica and iron oxides in thin bands in the clay horizon, presence of crystalline gibbsite along cracks, are all indicative of continuous process of solution from one part and deposition in another. 'Variscite Ferrian' ($FeAl(PO_4)_2 \cdot H_2O$), a new mineral was also investigated during the present investigation.

X-ray studies also reveal a semiquantitative picture of the mineral concentration and also reveal the presence of gibbsite, kaolinite, goethite, hematite and quartz in varying proportion with small to trace amount of boehmite, anatase. Variscite Ferrian (in a few samples), etc.

CHAPTER - V

GEO-CHEMISTRY OF MAJOR-OXIDES

CHAPTER - V

GEOCHEMISTRY OF MAJOR-OXIDES

V.1 : GENERAL STATEMENT :

Aluminium has been placed in group III-A of the periodic table. The atomic number of aluminium is 13 and its electronic configuration is K L M, Al^{3+} having 2 8 3 three units of positive charge, the valency of aluminium is 3.

Geochemistry is concerned with the physico-chemical factors that influence and/or control the depletion or precipitation and distribution of the chemical elements in the various zones of bauxite profile. The elements that are associated with rock in previous environment, may become separated in secondary environment, because their behaviour is now governed by an entirely different set of parameters which result in different dispersion characteristics for each element. Hawkes and Webb (1962) mentioned the mobility of some important elements, during weathering.

RELATION OF IONIC POTENTIAL AND HYDROXIDE FORMATION, (After Goldschmidt, 1937.)

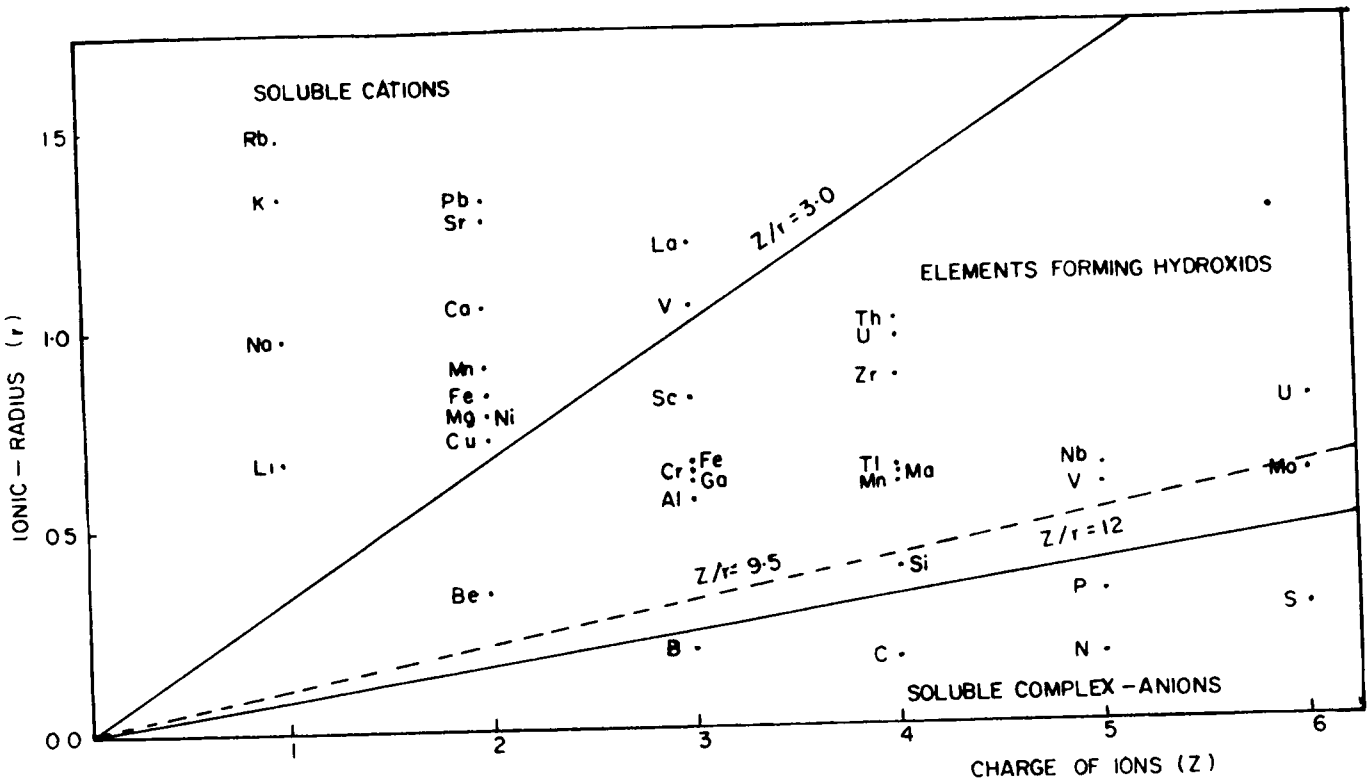


FIG. 6

TABLE - V : Relative mobility of various elements during weathering (After Hawkes and Webb, 1962).

Relative mobility	Major elements	Minor elements
Very mobile	S, Cl	Br, Mo, B, Se
Moderately mobile	Ca, Na, Mg, K	Zn, Ba, O
Moderately immobile	Si, Mn	Ni, Pb, Co, Cu, As, Sb
Very immobile	Fe, Al, Ti	Cr, rare earth

Goldschmidt (1937) by taking into consideration the ionic potential, subdivided the elements into three major groups (Fig. 6).

GROUP-I :

Having the lowest potentials and representing simple ionic compounds, these are readily soluble under sub-aerial conditions.

GROUP-II :

These are typically insoluble, being easily hydrolysed and precipitated in the form of hydroxides.

GROUP-III :

Possessing the highest ionic potential and forming complex anions with oxygen, are in contrast comparatively soluble.

In the study of secondary dispersion the parameters (z/r) ionic potential gives best idea about the geochemical behaviour of the elements during the process of lateritization. It explains the geochemical homogeneity between the elements with marked different chemical properties during migration and precipitation. According to the law of Goldschmidt the elements with same or similar ionic potentials will behave similarly.

Boyle (1974) stated that concentration of a single element rarely occurs in the earth. More generally, a suite of elements is concentrated in a particular deposit because of certain intrinsic chemical properties which depend essentially on their electronic configuration and hence their position in the periodic table. More

specifically, the migration and concentration of elements are controlled by Eh-pH conditions, complexation phenomena, hydrolytic reactions, colloidal phenomena, adsorption and base exchange reactions.

To achieve the objectives mentioned above, the systematic geochemical analyses of 60 representative samples of bauxitic profile selected from all the six hills and their adjacent parent rocks have been carried out for the detection of major oxides. The results of which are presented in Tables-VI to IX.

V.2 : DISTRIBUTION OF MAJOR OXIDES :

Goldschmidt (1937) considered the major elements as the products of sedimentation and grouped them as resistates, hydrolysates and oxidates, etc. Ten major oxides, Al_2O_3, Fe_2O_3, SiO_2, TiO_2, P_2O_5, CaO, MgO, K_2O, Na_2O, H_2O were analysed in the bauxites and parent rocks and their distribution from laterite at the top to charnockite at the bottom is presented below :-

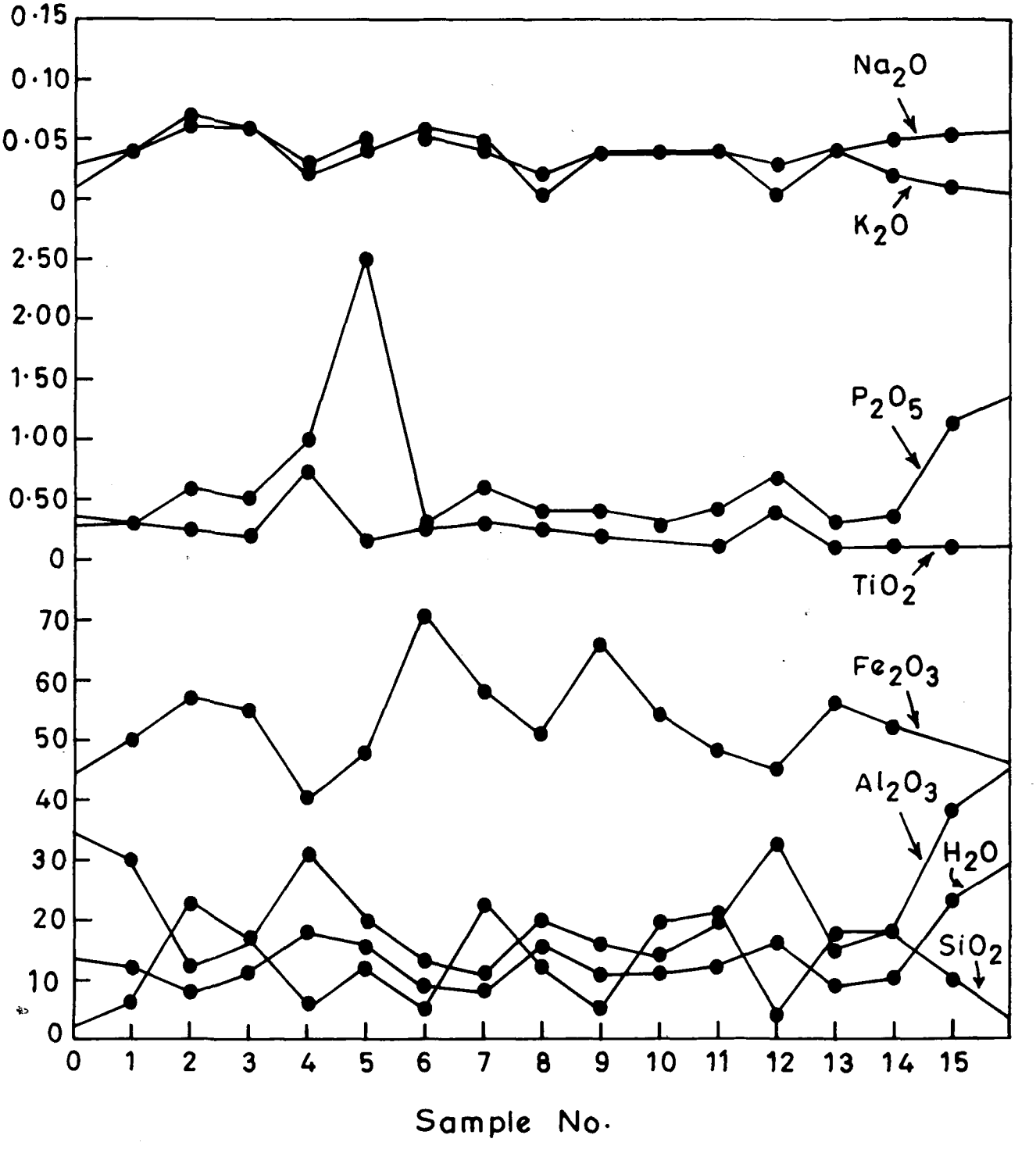


FIG.7. DISTRIBUTION OF MAJOR OXIDES IN LATERITES

V.2.1 : ALUMINIUM OXIDE (Al_2O_3) :

According to Goldschmidt aluminium is a lithophile element and during weathering it is liberated from the minerals and transported as hydrolysates (Mason, 1966).

The ionic potential of aluminium is about 6, makes the metal an important constituent of hydrolysates. Aluminium remain in solution in both acid and alkaline conditions, the precipitation of $Al(OH)_3$ on the other hand is favoured by neutral solution.

Aluminium is the chief constituent of bauxites in the form of alumina or hydroxides of alumina. Feldspar is the chief alumina bearing mineral in the source rocks.

Quantitative trend of alumina in lithomargic clay ranges from 13.52% to 37.92%, in laterites it ranges from 10.90% to 37.92 and in bauxites, it goes up to 40.89% to 59.60% (Figs. 7, 8, 9 & 10; Table-VI). The alumina percentages of the rock samples in the study area varies from 14.38% to 17.04% and reveals that alumina has enriched by 150% to 275% in the bauxites with respect to source rocks. The highest Al_2O_3 value (59.60%) is recorded from the central parts of the profile in Hill No. 1. High concentration of alumina in the samples

collected from the central part of the profile and scarp faces reveal high drainage intensity which favoured enrichment of alumina (Valeton, 1972). Variation in alumina content is also observed laterally which may possibly be due to the variation in the composition of source rocks and the intensity of operative processes locally. Ramam (1978) also emphasized that the gentle to moderate slope plays an important role in the formation of gibbsite (chief alumina bearing mineral).

V.2.2 : IRON OXIDE (Fe_2O_3) :

Goldschmidt (1937) placed iron into siderophile group, but it also resembles to the elements of chalcophile group.

It is second in importance and a major constituent of these bauxites. Ferro-magnesians are the chief iron bearing minerals in associated parent rocks, having Fe_2O_3 in between 3.48% to 5.23%.

Dispersion of iron in the Shevaroy bauxite samples reveal that Fe_2O_3 in lithomargic clay varies from 5% to 33%, in laterites it ranges from 28.30% to 57.65% and in the bauxites it fluctuates in between 3.35% and 32.50% (Figs. 7, 8, 9 & 10; Table-VI).

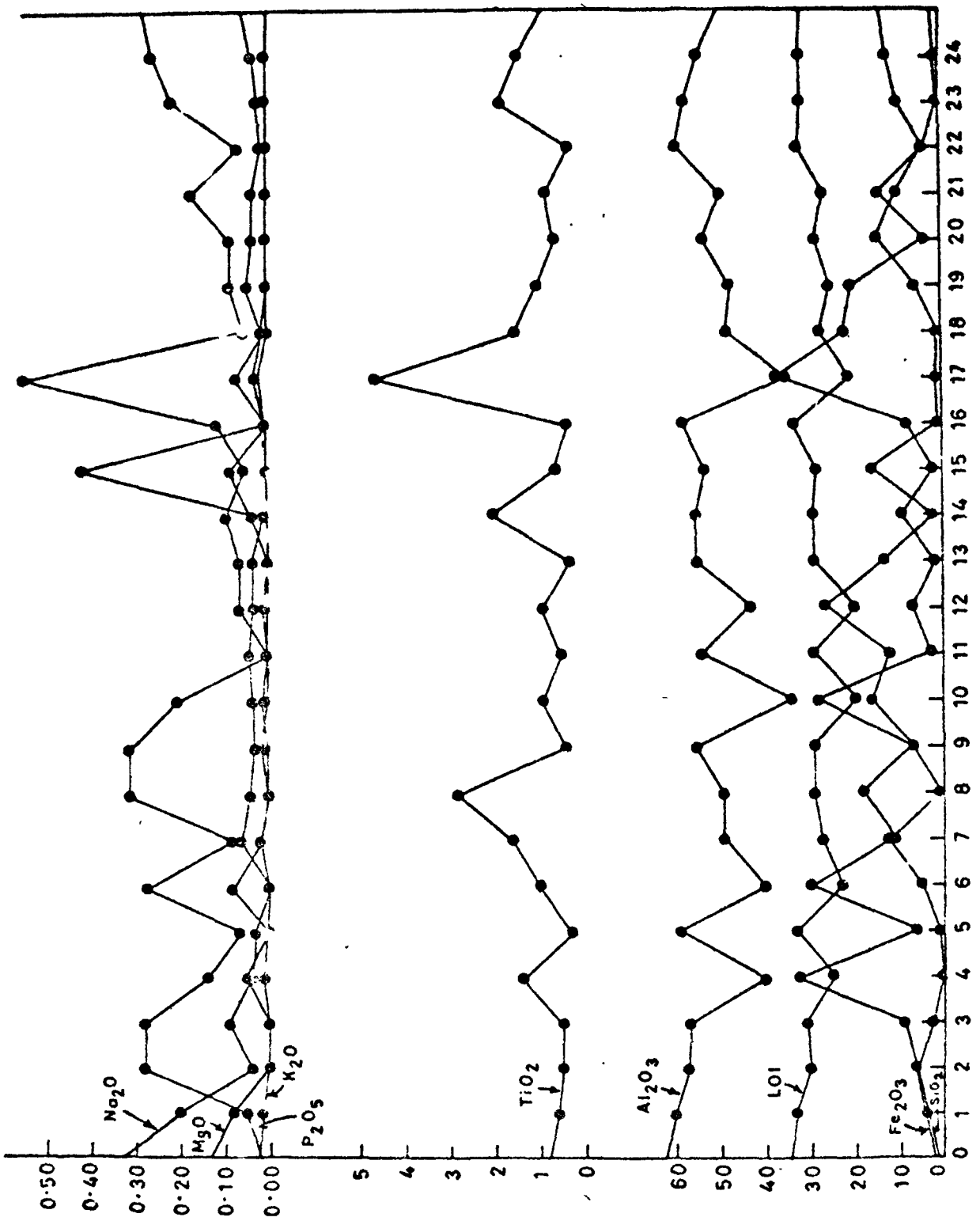


FIG. 8. DISTRIBUTION OF MAJOR OXIDES IN BAUXITES

There is an absolute enrichment of iron through impregnations which reaches up to 66% and 71% Fe_2O_3 in the upper iron cap, while iron values are much lower (4%) in the central part of the profile (in bauxitic ore body). Presence of this appreciable concentration could be due to alternating wet and dry season that favoured the upward movement of iron sesquioxides.

Aleva (1980), also opined that iron cap is formed due to the epeirogenic movement of iron during dry climate. Goldschmidt (1937) and Shapiro (1964) stated that suspension of ferric colloid may be stabilized by an intimately associated organic matter. Iron bacteria also helps in the oxidation of dissolved ferric-oxide. Goldschmidt further stated that fixation of iron takes place in the oxidizing conditions while reducing conditions promote solution.

V.2.3 : SILICON-OXIDE (SiO_2) :

It is a lithophile element and has an affinity for a silicate phase (Mason, 1966).

It is the most important constituent of the parent rocks which is removed in solution during the process of lateritization.

Dispersion of SiO_2 in the Shevaroy bauxite profile reveals that in the zone of lithomargic clay, it varies from 15.86% to 42.89% and in the laterites, it ranges from 5.96% to 22.85% while in the bauxites its concentration depletes very much and varies from 1.68% to 14.68% (Figs. 7, 8, 9 & 10; Table-VI).

Higher concentration of silica is recorded either from the zone of lithomargic clay or zone of strong resilicification. Free silica mostly in the form of unleached quartz is commonly observed in the crevices and cavities of the residuum.

Goldschmidt (1937) stated that according to climatic conditions, it behaves differently during the weathering process and hence gradual decrease in silica percentage from 42.89% (maximum) in the zone of lithomargic clay to less than 5% in the bauxitic zone was observed vertically.

Valeton (1972) emphasized the role of vegetation in silica fixation in the upper-most zone of the profile. In the present study, analytical data are in accordance with the X-ray studies which also reveal the presence of quartz (unleached). Zans (1959) stated that kaolinite (an intermediate phase in the process of lateritization), which is the main silica bearing mineral in the bauxites,

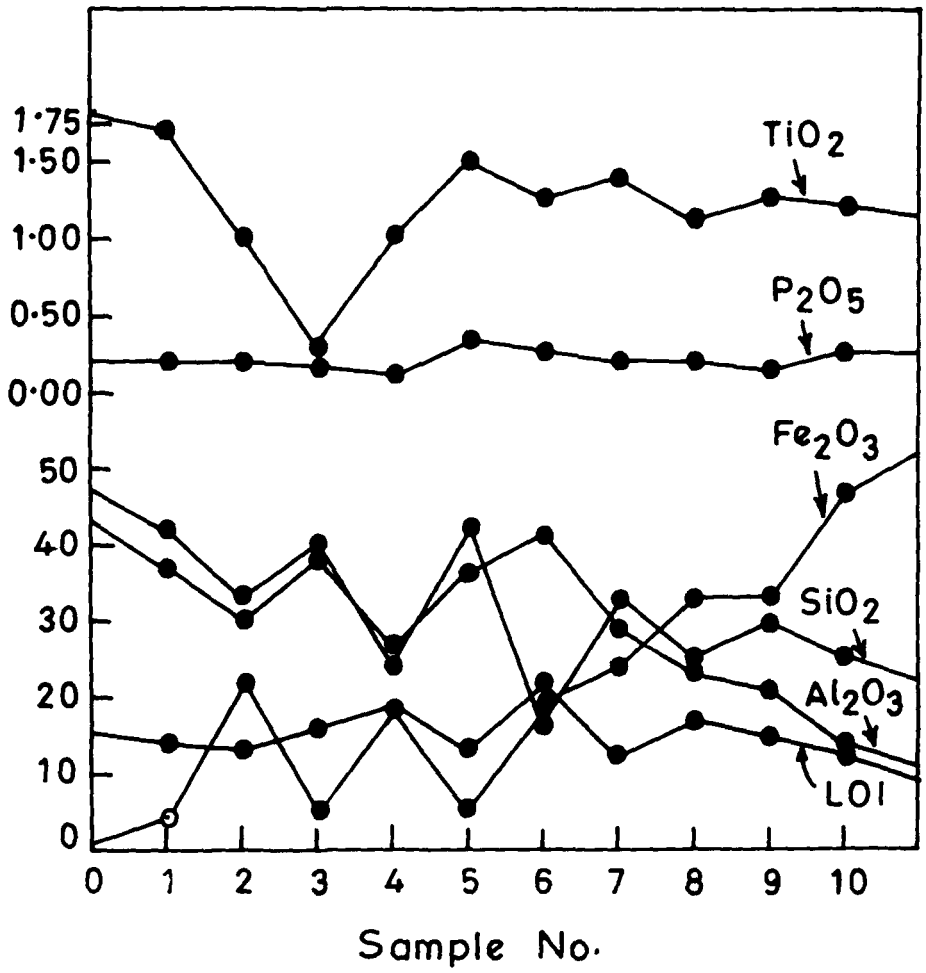


FIG.9 DISTRIBUTION OF MAJOR OXIDES IN THE LITHOMARGIC CLAYS

is commonly found intergrown with gibbsite. Secondary kaolinite resulting from resilicification also contributes the silica percentage in the bauxitic profile. On the other, Sahoo, et al. (1980), mentioned that an elevated gently sloping terrain, fractured bed rock and fairly continuous gradient permitted efficient leaching of SiO_2 and its subsequent removal in a mildly acidic environment.

It is, therefore, inferred that higher percentage of silica in the Shevaroy bauxites may possibly be due to lack of good drainage conditions and textural behaviour (non-porous and impervious) of the parent rocks.

V.2.4 : TITANIUM-OXIDE (TiO_2) :

It is strongly lithophile in character, less mobile and posses strong resistance to chemical weathering as compared to the others (Mason, 1966). Hawkes and Webb (1962) also categorized the titanium as very immobile element just like Fe and Al.

In the study area, the quantitative variation trend of TiO_2 in lithomargic clay ranges from 0.99% to 1.67% and its concentration in laterites varies from 0.27% to 2.50% and in the bauxitic zone in between 0.29% to 4.60% (Figs. 7, 8, 9 & 10; Table-VI). Titanium concentration in the

parent rocks varies from 0.25% to 0.73%. Comparison between titania content in parent rocks and that of the bauxite samples reveals that it has enriched up to 500% with respect to source rocks, because of its low mobility and least solubility.

Rankama and Sahama (1949); Hartman (1953); and Migdisow (1960) observed, highest enrichment of titanium in the bauxites during weathering, which is also in accordance with the present investigations.

High concentration of titanium even in the lithomargic zone could be explained by its high specific gravity and resistant to weathering.

Valeton (1972) stated that titanium content in the bauxites is governed by the amount of titanium available in the source rocks and by the degree of mobilization. This statement is well in agreement with the results obtained in the present study in which titania concentration is low and uniform in almost all the parent rock samples (Table-VII).

V.2.5 : PHOSPHORUS-PENTA-OXIDE (P_2O_5) :

Goldschmidt (1937) classified phosphorus as a siderophile element. Most of the bauxites are low in

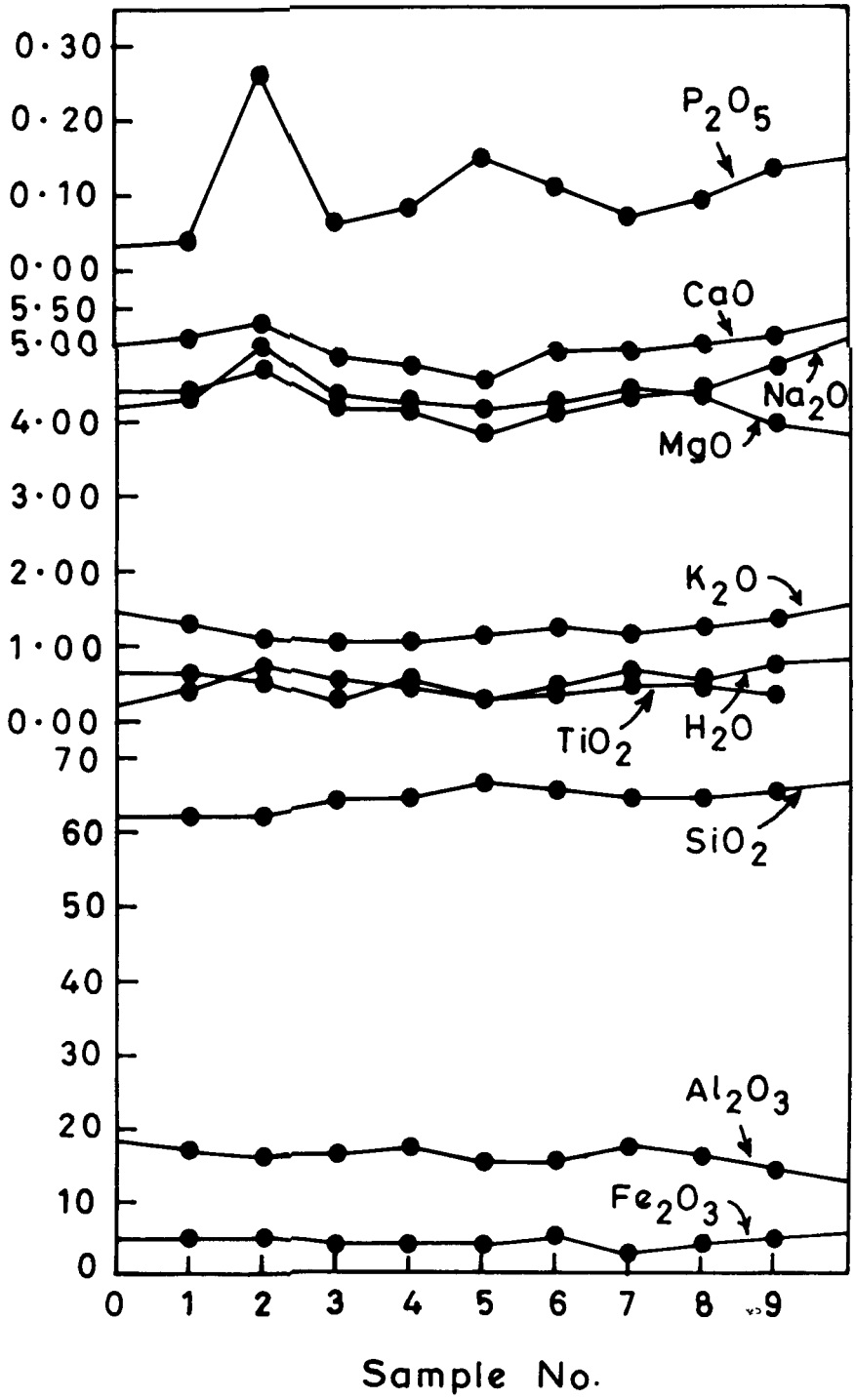


FIG.10. DISTRIBUTION OF MAJOR OXIDES IN PARENT ROCK

phosphorus content. Khalighi (1968) investigated the distribution of phosphorus in a number of bauxite and laterite profiles on basalts and charnockites in India. He concluded that there is no simple relationship between phosphorus and any one of the major elements and that the values of phosphorus fluctuate widely in various samples. Its quantitative variation trend in the study area varies from 0.11% to 0.33% in the zone of lithomargic clay and 0.08% to 0.74% in laterites, whereas in the bauxites it ranges from traces to 0.31%. Few samples collected from Hill No. 2, from upper-most lateritic zone, show appreciable concentration of P_2O_5, which goes up to 28.71% (Figs. 7, 8, 9 & 10; Table-VI). X-ray studies of the same samples reveal the presence of phosphatic mineral - Variscite-ferrian (Table-III) which explains the high phosphatic concentration in these samples.

Presence of apatite as an accessory mineral in the parent rocks may contribute in the concentration of P_2O_5 in the upper-most lateritic zone, where it follows the same trend of enrichment as that of iron. It can be easily accommodated in the mineral structure because of its isomorphic substitution.

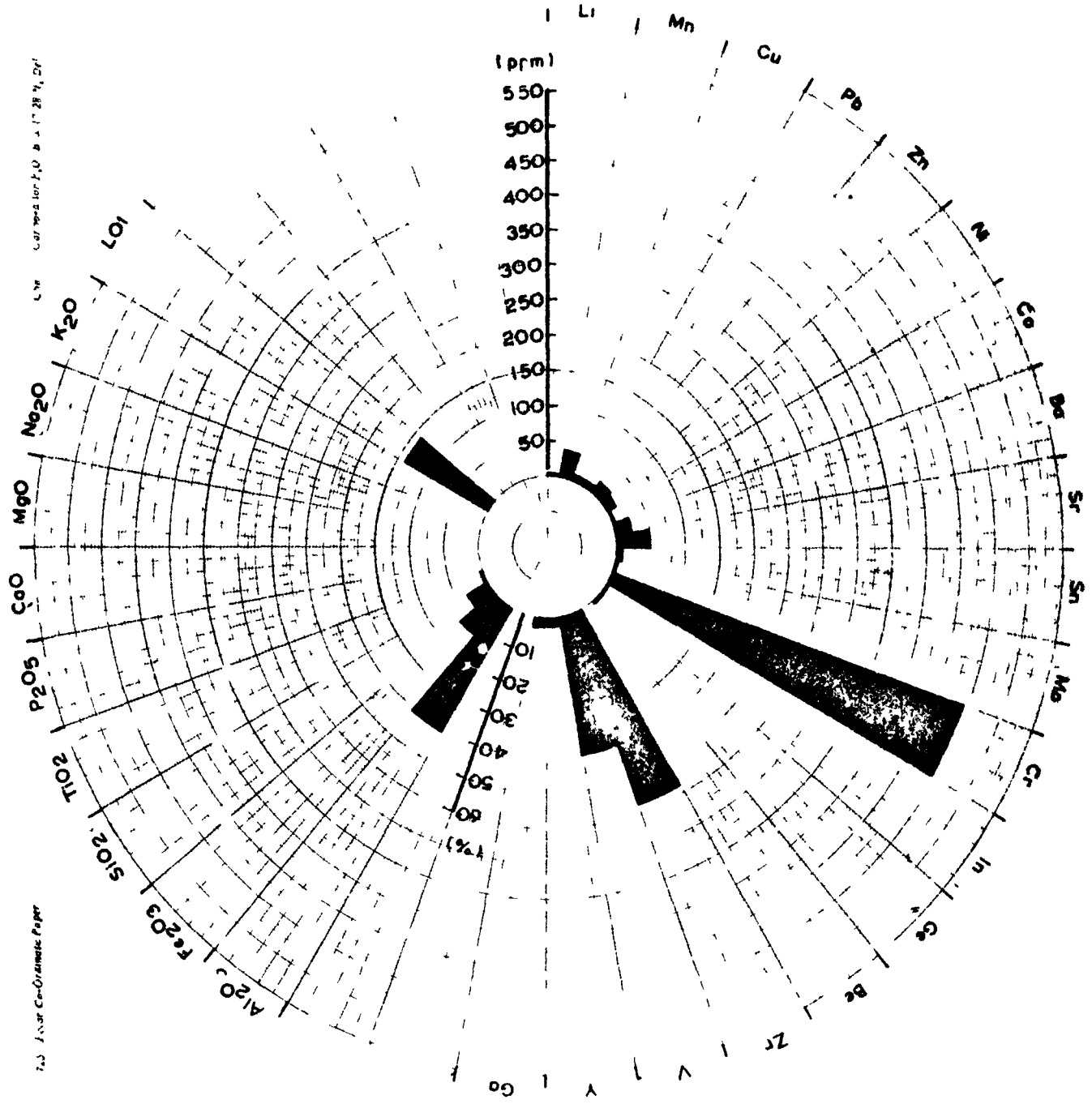


FIG II GEOCHEMICAL VARIATION DIAGRAM OF MAJOR OXIDES AND TRACE METAL CONCENTRATION IN BAUXITES

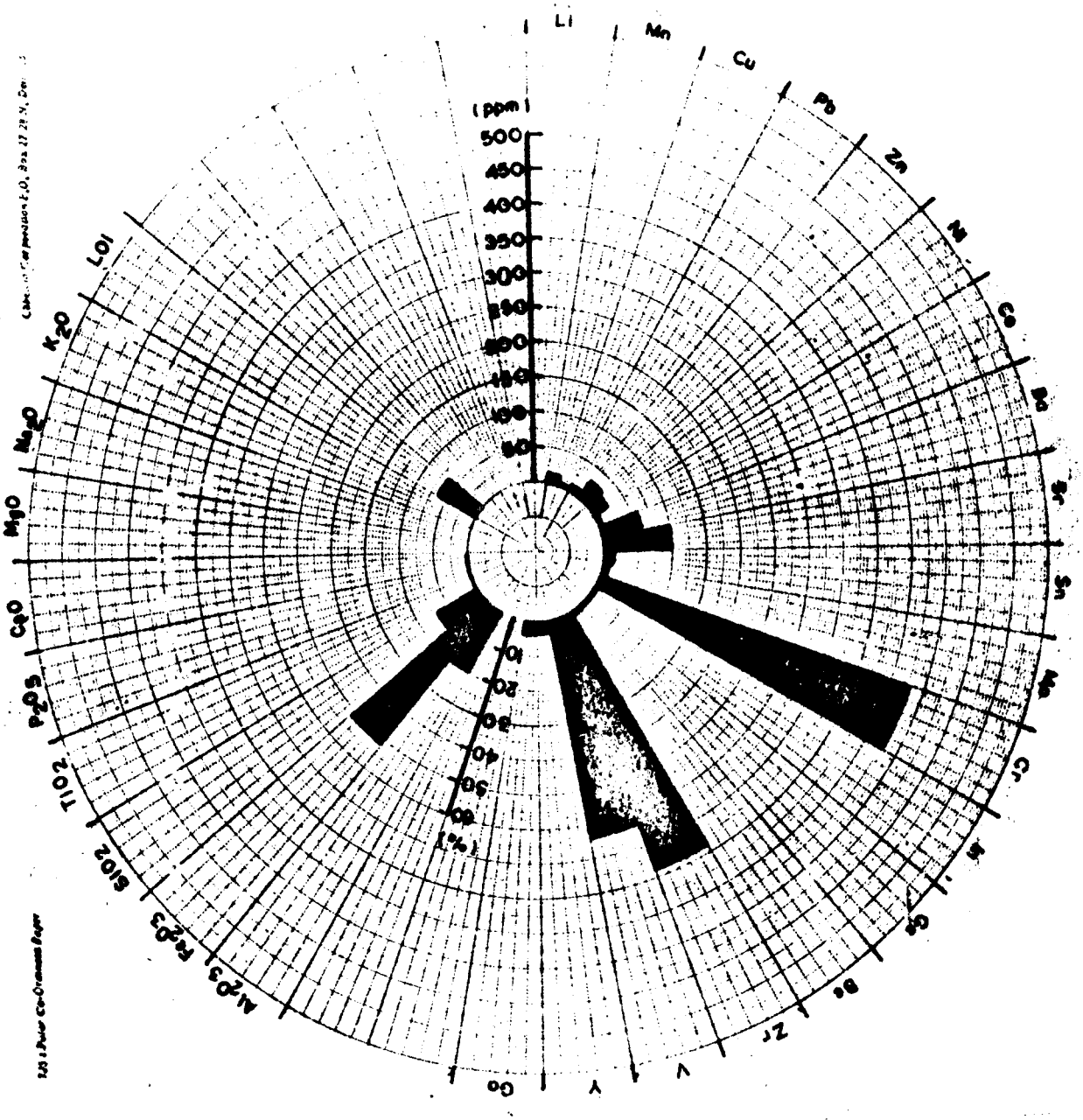


FIG.12 GEOCHEMICAL VARIATION DIAGRAM OF MAJOR OXIDES AND TRACE METAL CONCENTRATION IN LATERITES

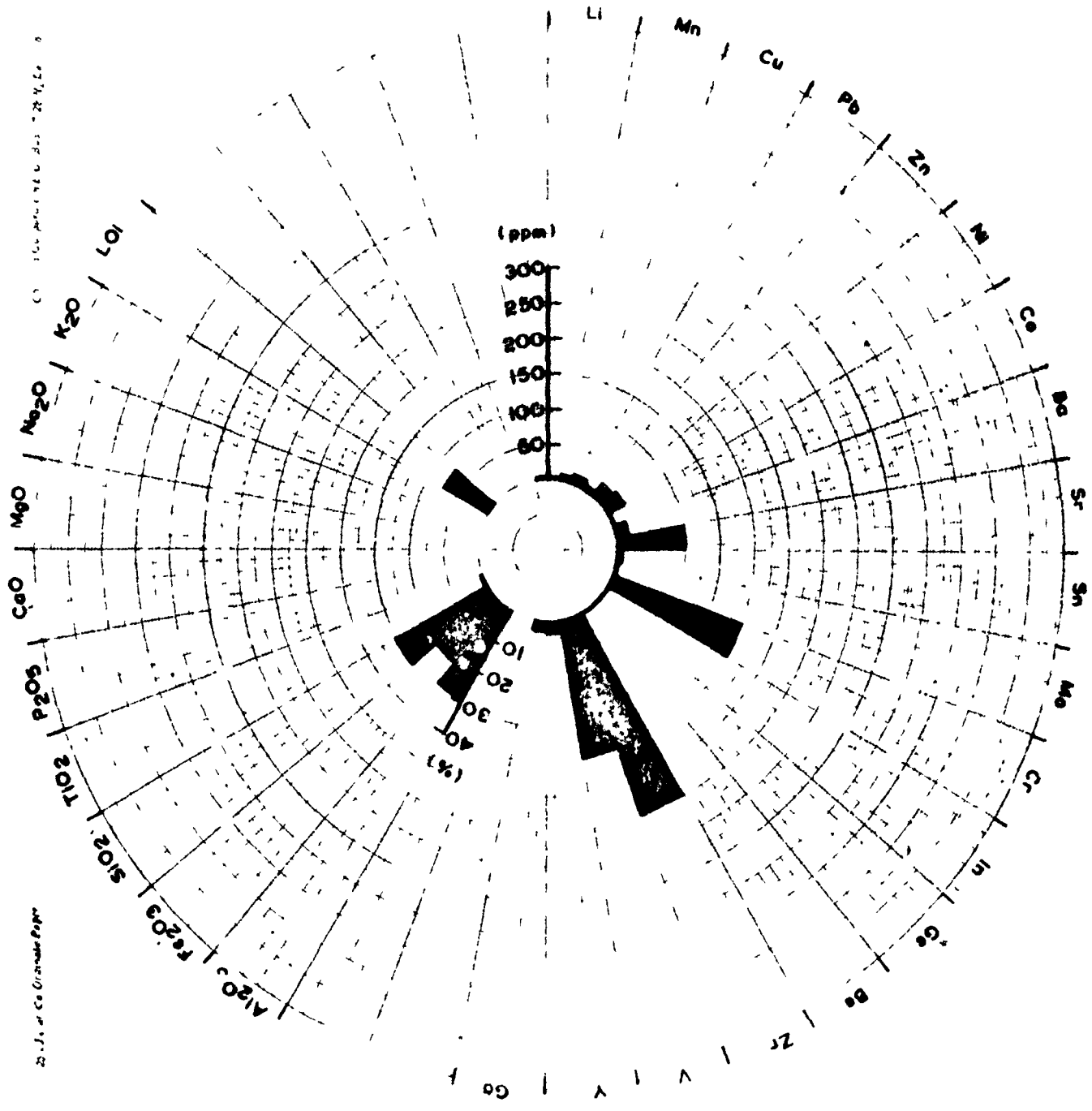


FIG. 13 GEOCHEMICAL VARIATION DIAGRAM OF MAJOR OXIDES AND TRACE METAL CONCENTRATION IN LITHOMARGIC CLAYS

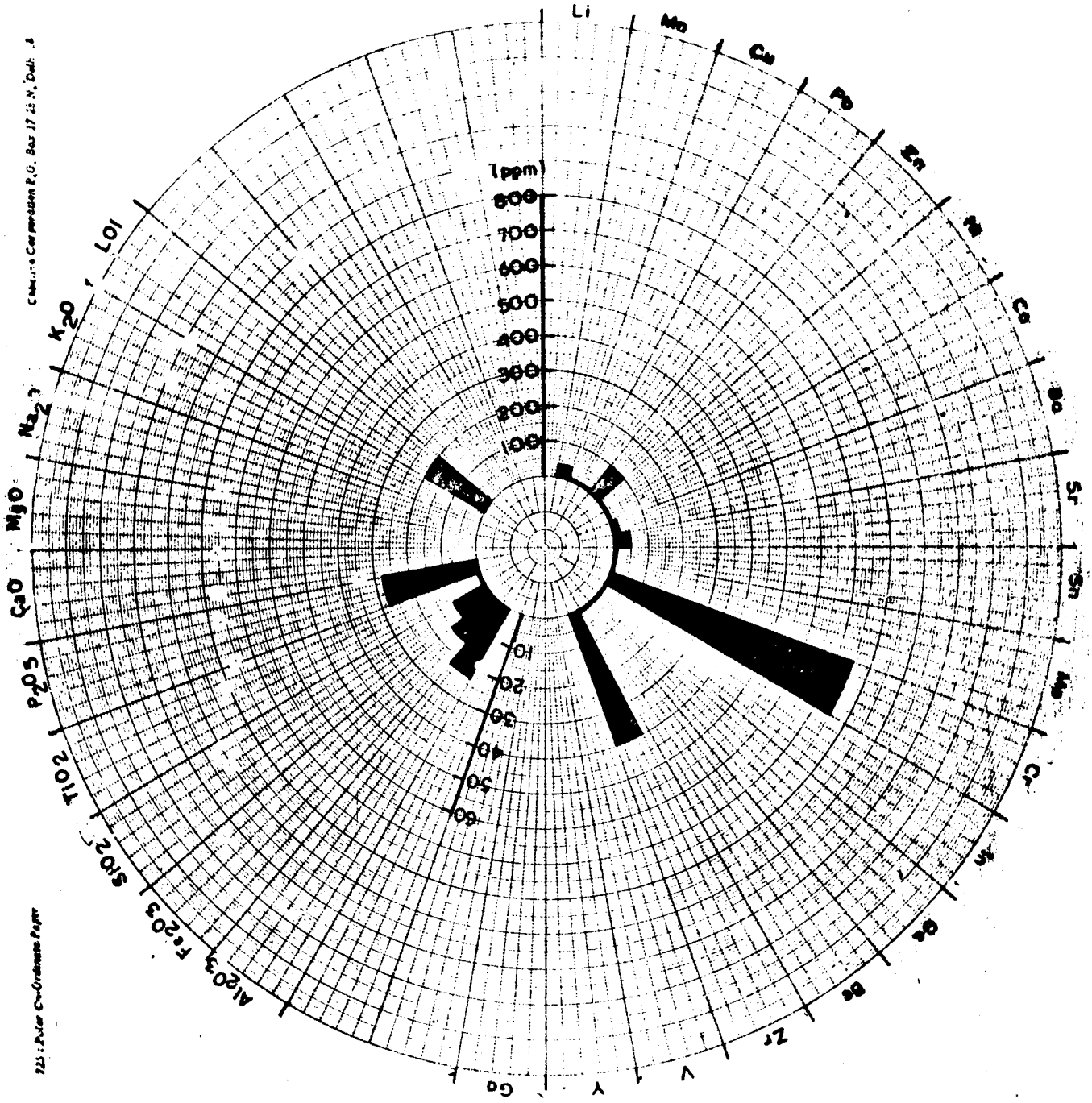


FIG.14 GEOCHEMICAL VARIATION DIAGRAM OF MAJOR OXIDES AND TRACE METAL CONCENTRATION IN PHOSPHATIC BAUXITES

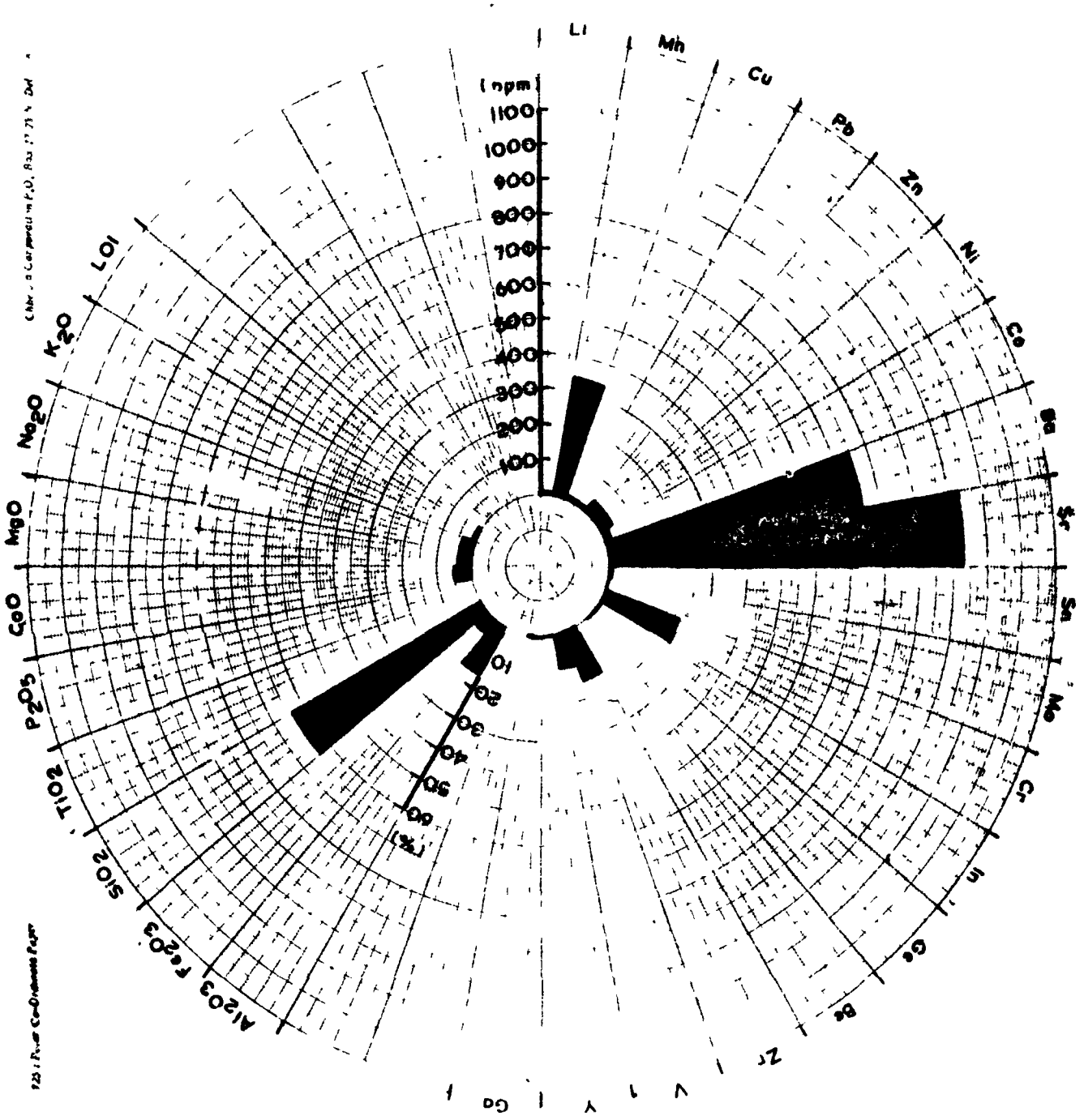


FIG. 15 GEOCHEMICAL VARIATION DIAGRAM OF MAJOR OXIDES AND TRACE METAL CONCENTRATION IN PARENT ROCKS

Ahmad (1979) stated that a considerable amount of phosphorus remains in the resistates as undissolved apatite. The dissolution of phosphorus is notably controlled by the organisms. It can be precipitated both by chemical activity as well as by biochemical processes.

Exceptionally higher concentration of P_2O_5 in these samples might be due to oxidation of iron which favoured the fixation of phosphorus as very insoluble basic or normal ferri-phosphate or perhaps rather in the form of ferri-phosphoric acid as also mentioned by Goldschmidt (1937). The reduction of iron favours the renewed solution and thereby mobilization of phosphoric acid, as shown by the limnological work of W. Einsele (1938). Zans (1959) also observed an exceptionally higher percentage of P_2O_5 (16-28%) in some of the deposits and explained that in the bauxites, phosphorus is also present in the form of ferruginous and aluminous phosphates. Phosphorus is also regarded as a part of the initial sediments, precipitated from solution. The crystallization of the bauxite gel substance during differentiation results in the formation of aluminous phosphates. Zans (Loc. cit.) considered francolite, evansite and other phosphatic minerals as secondary products. These are similar to the new reported mineral - Variscite-ferrian, a ferruginous aluminium

phosphate in the present study, is well in agreement with above mentioned observations.

Ray Mahashay, et al. (1984) studied the high ion exchange capacity of the laterites, developed over Precambrian crystalline rocks near Calicut, also mentioned the high efficiency for phosphate uptake. They explained the mechanism involved in phosphate uptake by anion exchange. According to them in laterites, phosphate uptake is accentuated by the presence of positively charged iron-hydroxide colloids and therefore they considered it very important to make the lateritic soil fertile, which are commonly deficient in nutrients. They also held responsible OH^- as an exchangeable ion in phosphate uptake.

While aggreeing to the above observations, the author is of the opinion that the mineral Variscite-ferrian is of secondary origin (non-contemporaneous to the bauxites). It is deposited on the surface or near surface conditions in the voids by the action of phosphatic meteoric water on pre-deposited laterites/bauxites.

V.2.6 : LOSS ON IGNITION (H_2O) :

Water content of the samples of the bauxitic profile is determined as ignition loss. Much of the

loss in weight is recorded particularly in the bauxitic zone. According to Roy Chowdhary et al. (1964), the LOI could form a reliable guide to aluminium content of the bauxite samples, under certain conditions, provided hematite and gibbsite are the only iron and aluminium minerals respectively and clay mineral content is negligible.

In the study area, H_2O content varies from 11.98% to 19.15% in the zone of lithomargic clay. In laterites, it varies from 8.11% to 22.53%, while it goes up to 20.17% to 32.53% in bauxitic zone (Figs. 7, 8, 9 & 10; Table-VI). The excess of water in bauxites may principally be due to its more hydrated nature.

V.2.7 : CALCIUM-OXIDE (CaO) :

Calcium oxide falls in the lithophile group (Goldschmidt, 1923). It has more mobility like Mg, Na and K (Mason, 1966).

Concentration of calcium in the entire Shevaroy bauxite profile is negligible or only in traces as compared to the associated source rocks with varying CaO between 4.50% and 5.11% (Figs. 7, 8, 9, & 10; Table-VI).

Extremely low calcium concentration in the bauxite samples may possibly be due to its high mobility during weathering because feldspars are the chief calcium bearing minerals in the host rocks from which it is removed due to intense leaching.

V.2.8 : MAGNESIUM-OXIDE (MgO) :

It is a lithophile element having high mobility (Mason, 1966). It is one of the important constituent of the ferro-magnesian minerals in the parent rocks, and therefore its higher concentration in the bauxites may be expected. Due to its very low concentration in these bauxites like calcium it appears that Mg might have leached out during the process of lateritization.

Magnesium concentration in the samples of complete bauxite profile is quite negligible (3.89% to 4.96%; Table-VI), which reflects that it has leached out during the process of lateritization. Figures-7, 8, 9 & 10, reveal the concentration in various samples of the bauxite profile.

V.2.9 : SODIUM-OXIDE (Na_2O) & POTASSIUM-OXIDE (K_2O) :

Sodium and potassium are strongly lithophile elements (Goldschmidt, 1937). Wedepohl (1970) discussed their chemical characters and mentioned that they differ from many other groups of elements especially in their mobility. The uniform valancies of the alkali metals, all of which form univalent positive ions and high solubility of most of their compounds are the properties which are exceptionally present in these elements.

Feldspars and alkali ferro-magnesians are the main constituents of the parent rocks, hence they must have significant contents of Na_2O and K_2O. Dispersion of these alkali-oxides reveals very low concentration in the bauxites and do not reach above 0.06% which reflect a remarkable depletion in its contents as compared to the source rocks that contain 3.84% to 4.72% of Na_2O and 1.03% to 1.38% of K_2O (Table-VII). Low concentration of these oxides in the bauxite profile could be due to their high solubility during the initial stages of weathering and their leaching thereafter which is in agreement with the known behaviour of Ba and Sr (Goldschmidt, 1954).

The depletion of these elements during the formation of bauxites from nepheline-syenite at Arkansas has also been demonstrated by Gordon and Murata (1952) and Wolfendon(1965).

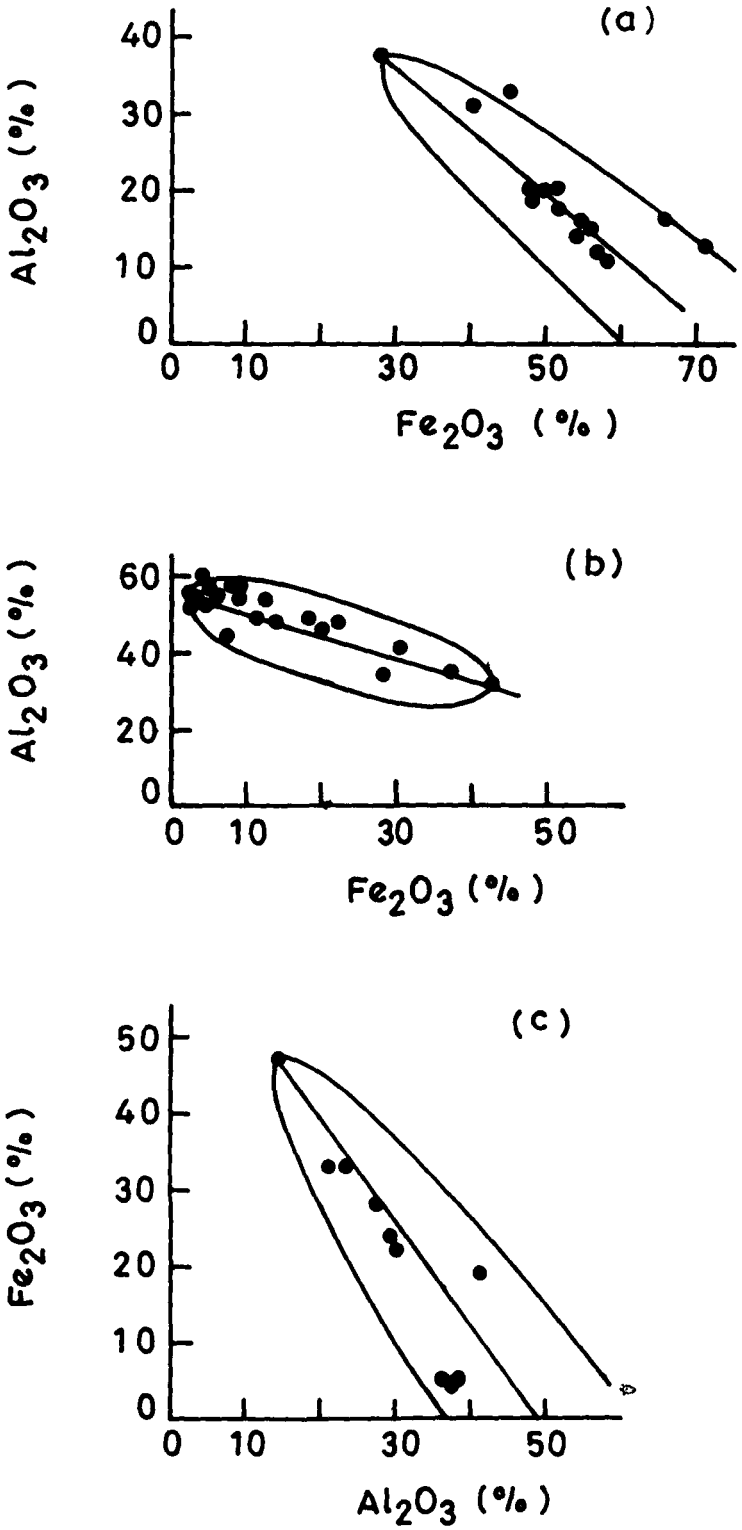


FIG.16. CORRELATION DIAGRAM OF Al_2O_3 Vs. Fe_2O_3 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

V.3 : INTER-RELATIONSHIP BETWEEN MAJOR OXIDES :

An attempt has been made to study the relationship trend of alumina with other oxides and inter-relationship between the other oxides themselves also in the Shevaroy bauxite profile. It may be helpful in determining the parameters of geochemical and physico-chemical environment which may reflect the processes active during the genesis of these bauxite deposits.

V.3.1 : *RELATIONSHIPS WITH* Al_2O_3 :

V.3.1.1 : Fe_2O_3 vs. Al_2O_3 :

There exists a negative relationship between Fe_2O_3 and Al_2O_3 over most part of the profile. Though in some parts of the laterite and clay horizon they are nearly in equal amounts and the two curves cross each other. The inverse relationship is most conspicuously seen in the bauxite zone in which the two curves are mirror image of each other (Figs. 7, 8, 9, 16 a & b).

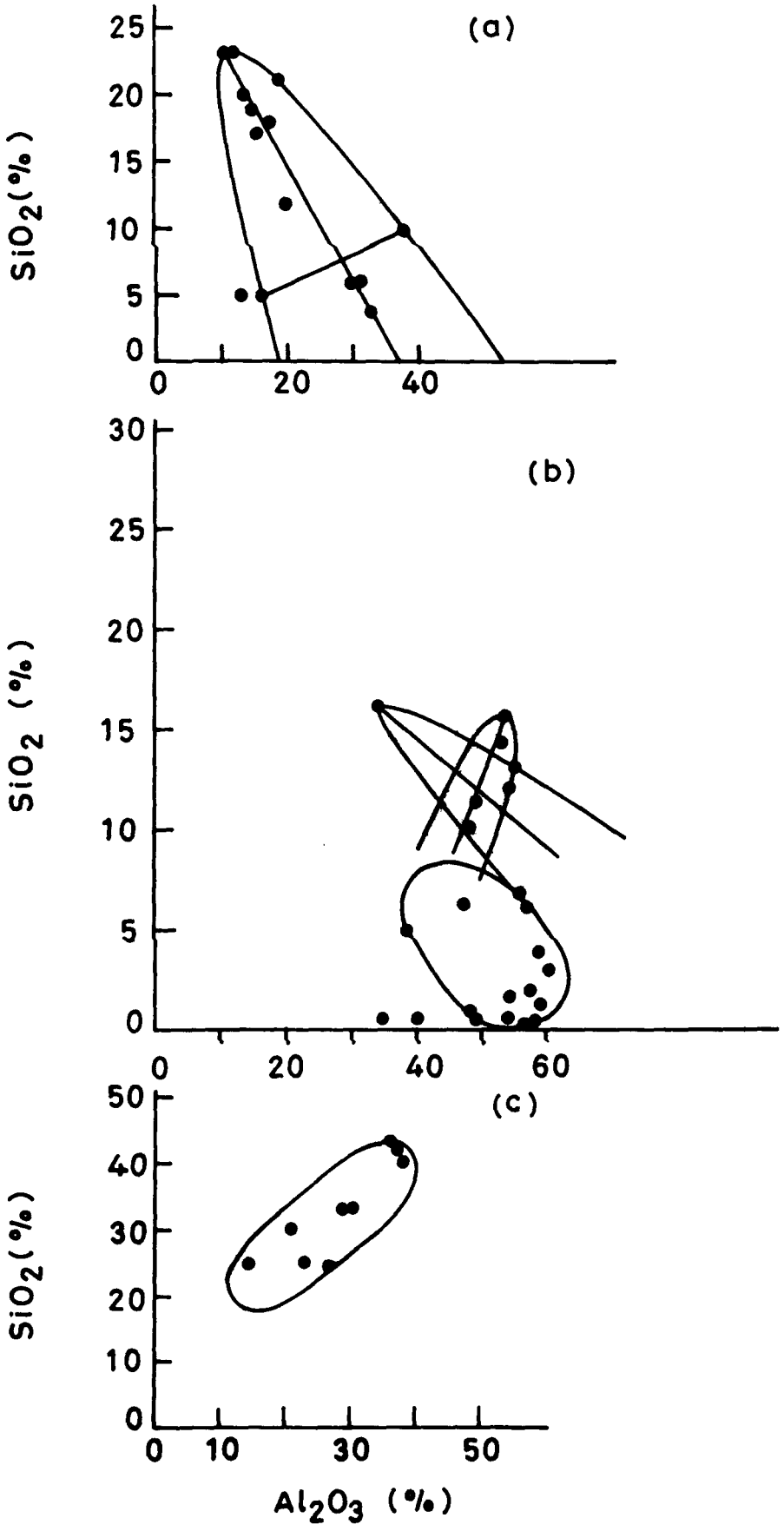


FIG. 17 CORRELATION DIAGRAM OF SiO_2 Vs. Al_2O_3 IN
(a) LATERITE
(b) BAUXITE

In the lateritic zone, Fe_2O_3 trend is indistinct, which gives an indication of its enrichment in this zone (Fig. 16 c).

An antipathetic relationship and or different geochemical behaviour between these two major oxides is governed by the physico-chemical conditions of the residuum. Norton (1973) observed that the low pH and high Eh are conducive for the precipitation of iron hydroxides, and low to intermediate pH and low Eh favours the fixation of aluminium hydroxides. Similar trend was also observed by Rahman (1978) who stated that in the early stage of bauxitization, increasing degree of drainage with increasing speed of SiO_2 removal, leads in the relative enrichment of aluminium. Commonly there is an intergrowth of Al and Fe minerals in gibbsite.

V.3.1.2 : $\underline{SiO_2 \text{ vs. } Al_2O_3}$:

SiO_2 has antipathetic as well as significant relationship with Al_2O_3 (Figs. 17 a, b & c). In the bauxite and laterite zones the SiO_2 has an inverse relationship with Al_2O_3. In the zone of lithomargic clay the inverse relationship is not very much perfect, because in this zone silica percentage reaches up to 42.89% as compared to alumina (13.52%).

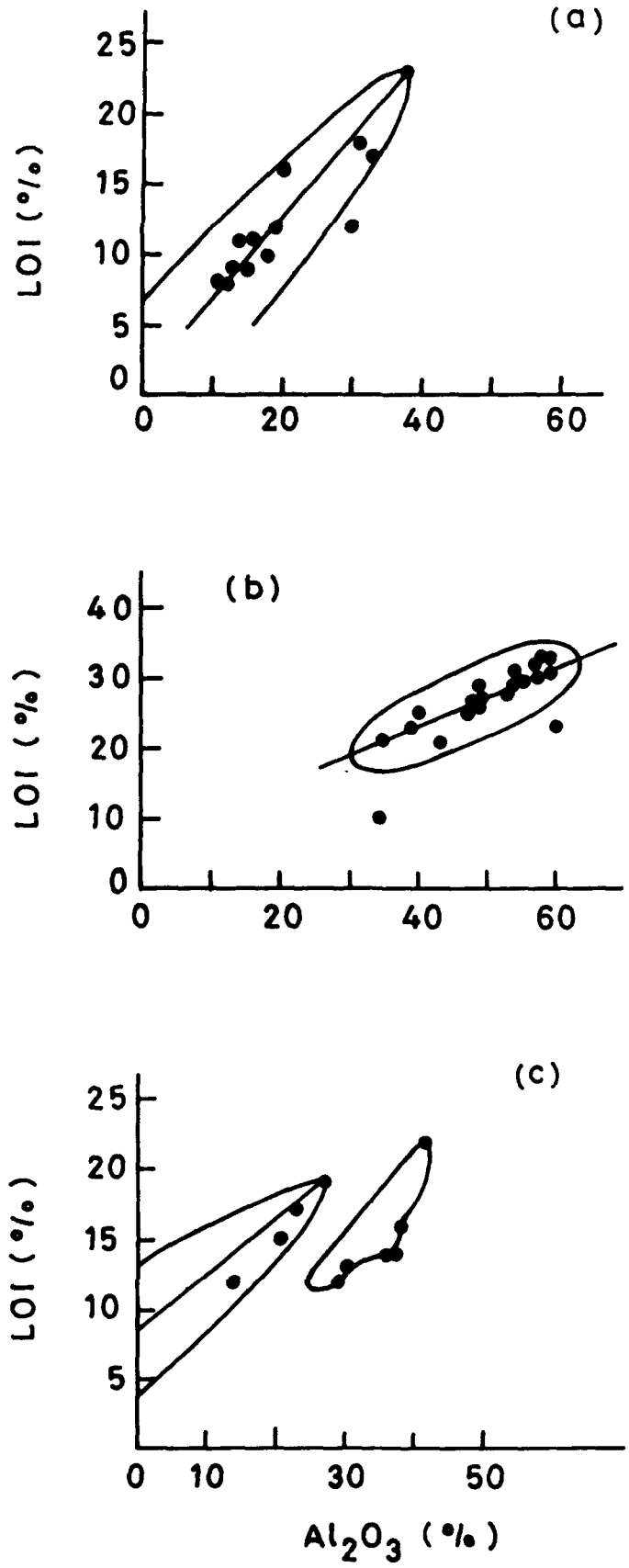


FIG. 18 CORRELATION DIAGRAM OF LOI Vs. Al_2O_3 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

Rahman (1978) stated that this is the most obvious relationship, because in bauxitization there is a gradual removal of silica and enrichment of alumina might be due to similarity in ionic radii (Si^{4+} = 0.42 A^{o}). (Al^{3+} 0.57 A^{o}) that might cause the replacement of silica by alumina.

Kronberg et al. (1982) stated that enrichment of alumina and removal of silica is a function of drainage intensity. Good drainage conditions near the surface favour the formation of hydroxide of aluminium, while the acidic conditions and sluggish drainage below the surficial zone, especially at the contact of ore body with the parent rock, facilitate the formation of clay zone. In the clay zone, therefore, silica concentration may be expected to be more than alumina concentration while in the upper lateritic or bauxitic zones, alumina concentration will dominate over the meagre concentration of silica.

V.3.1.3 : LOI vs. Al_2O_3 :

LOI maintains positive relationship with Al_2O_3 (Figs. 18 a, b & c). As shown in figure, the LOI curve is more or less parallel to Al_2O_3, which reflects a positive relationship. It thus points out that major

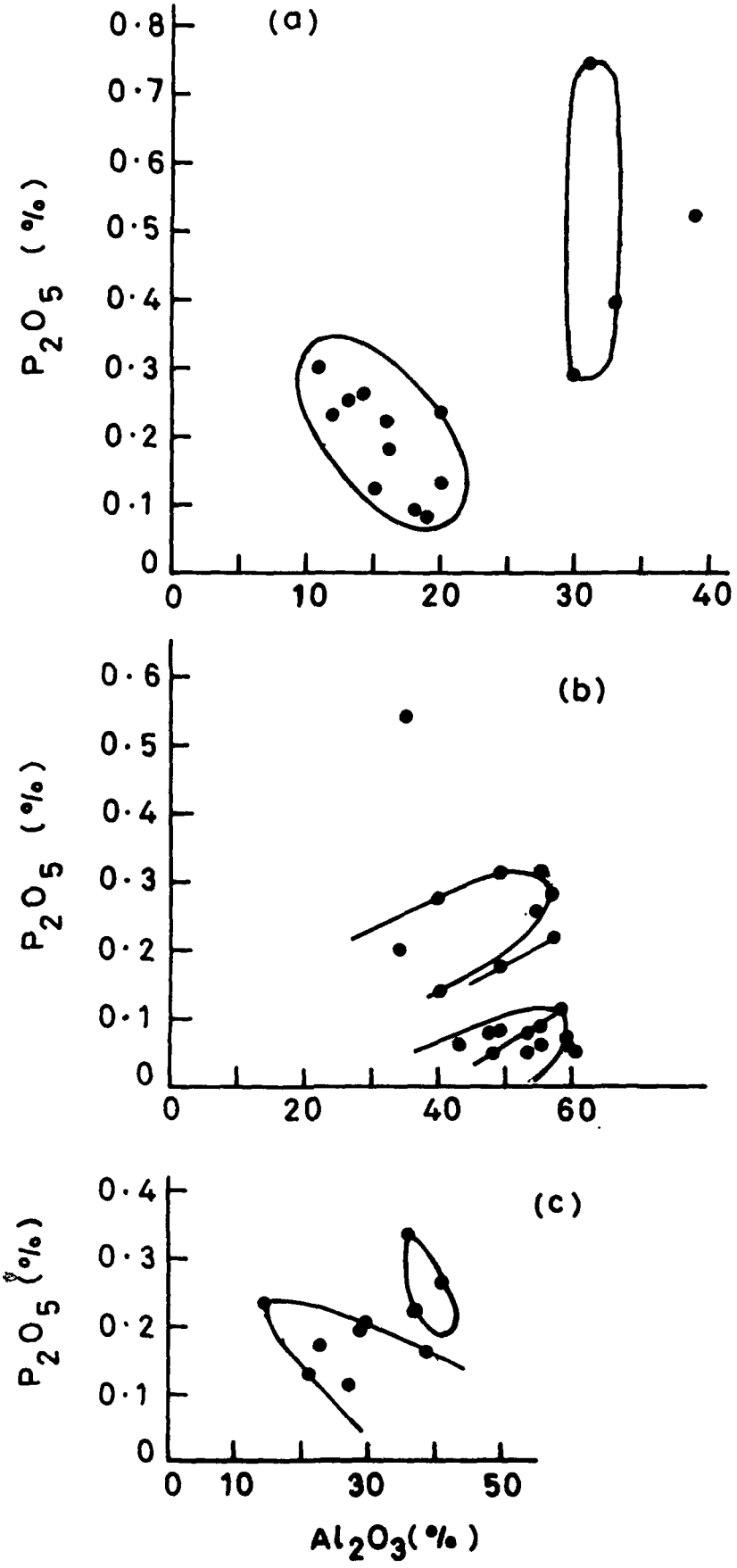


FIG. 19 CORRELATION DIAGRAM OF P_2O_5 Vs. Al_2O_3 IN (a) LATERITE

proportion of water molecules are locked up with alumina. The curve shows direct relationship to the Al_2O_3 in the bauxite zone, but these two curves do not show any definite trend over the major part of the clay and lateritic zones. This accounts for the higher proportion of iron hydroxides in these horizons which also contribute to the LOI. Even monohydrate aluminium mineral does not show positive relationship with LOI.

Roy Chowdhary et al. (1964) and Panicker, et al. (1973) also reported a linear relationship between LOI and Al_2O_3, keeping in view of the presence of goethite and such other minerals.

V.3.1.4 : $\underline{P_2O_5}$ vs. $\underline{Al_2O_3}$:

There exists a positive relationship between P_2O_5 and Al_2O_3 in the bauxite samples. While the lateritic and clayey samples show antipathetic relationship (Figs. 19 a, b & c). This inverse relationship may possibly be due to the difference in ionic radii of Al^{3+} (0.57 A^o) and P^{5+} (0.35 A^o) and positive relationship in the bauxite samples might be possibly due to similar set of required physico-chemical conditions at the time of deposition or precipitation.

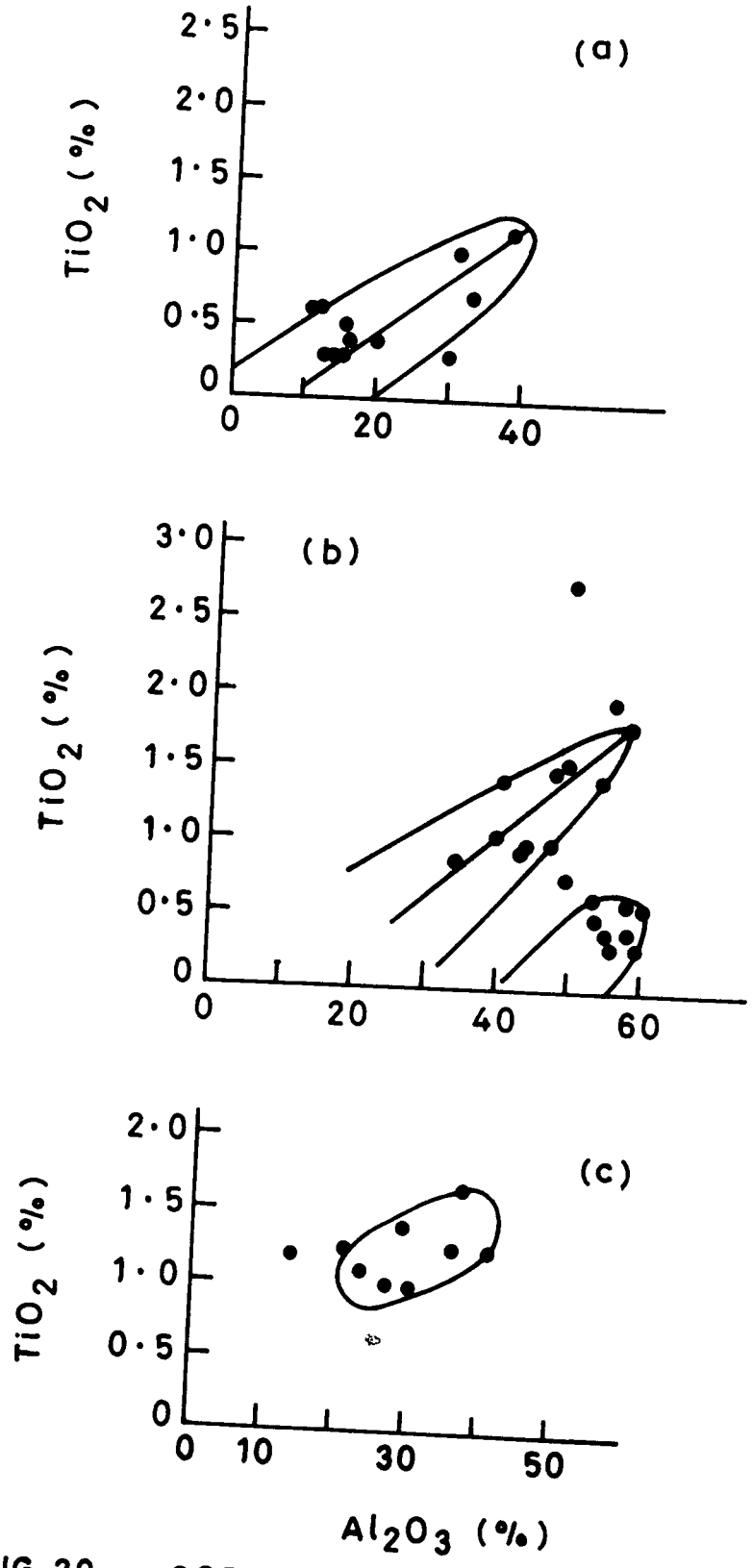


FIG. 20 CORRELATION DIAGRAM OF TiO_2 Vs. Al_2O_3 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

V.3.1.5 : $\underline{TiO_2 \text{ vs. } Al_2O_3}$:

Positive and significant relationship between TiO_2 and Al_2O_3 has been noticed in majority of the samples in the bauxitic zone. Same trend was also observed in the lateritic zone with a difference in slope of the correlation curve which is steeper in bauxites than in the laterites (Figs. 20 a, b & c). It reveals that titanium is partitioned preferentially in Al_2O_3 i.e. more in bauxites than in the laterites. Same does not hold true for lithomargic clay, because no perfect relationship in this zone has been observed.

Migdisow (1960) stated that titanium enrichment is highest in bauxites during weathering. Valeton (1972) mentioned that enrichment of titanium is governed by the amount of titanium available in source rocks. Goldschmidt (1950), Washington and West (1958) also noticed the enrichment of titanium together with aluminium during lateritic weathering.

Loughman, et al. (1961) mentioned that the TiO_2 content, increases proportionally to gibbsite and bears no relationship with kaolinite. This observation is also in conformity with the Indian bauxites derived from Deccan-basalts (Roy Chowdhary, et al., 1964).

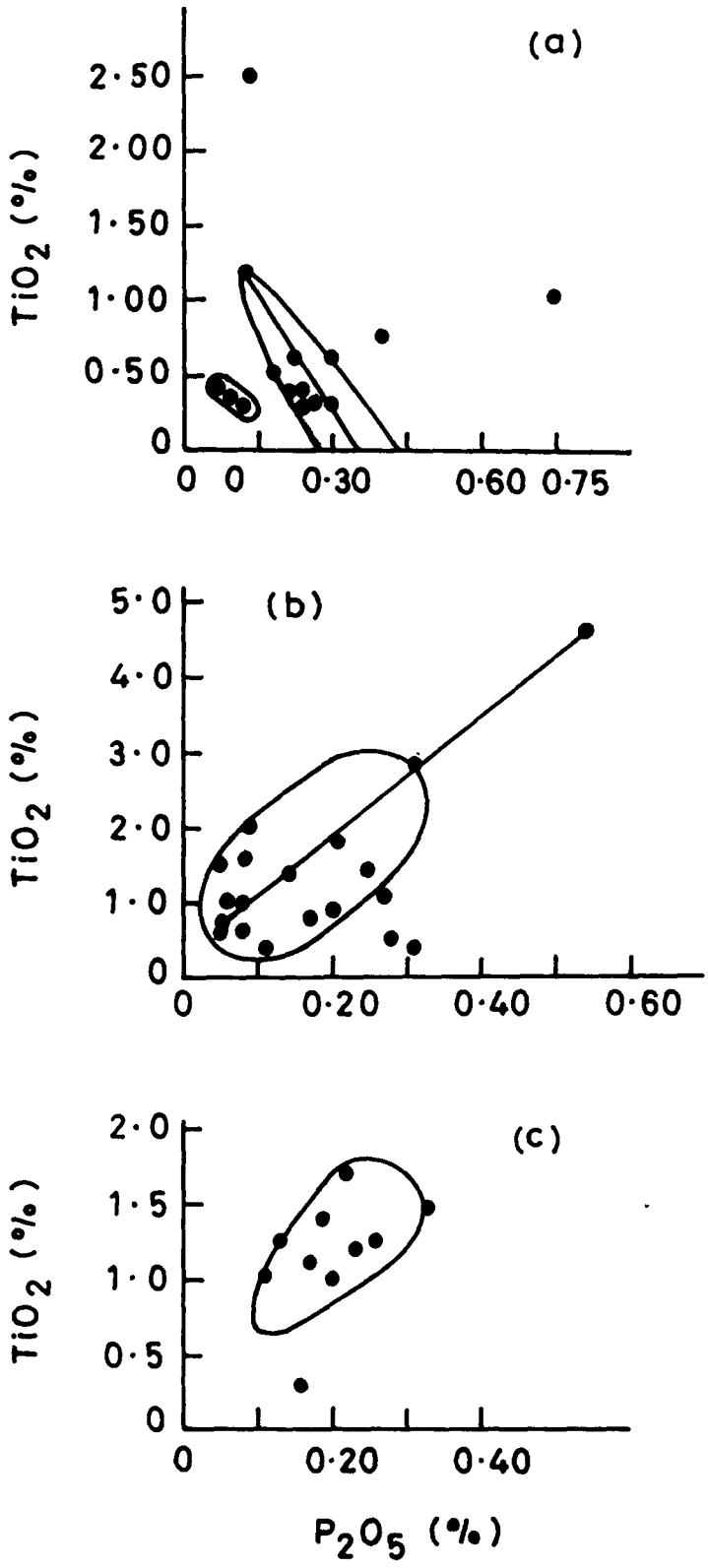


FIG. 21 CORRELATION DIAGRAM OF TiO_2 Vs. P_2O_5 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

Paul (1969) stated that due to closeness in ionic potentials between Ti^{4+} (2.43) and Al^{3+} (2.45), the entry of titanium into crystal lattice of gibbsite may be accomplished by endocryptic replacement of Al^{3+} by Ti^{4+} with simultaneous replacement of OH^- by O_2^- without disturbing the crystal chemical equilibria.

V.3.1.6 : $\underline{P_2O_5 \text{ vs. } TiO_2}$:

Inter-relationship between P_2O_5 and TiO_2 for the samples of laterites, bauxites and lithomargic clay is shown in Figures-21 a, b & c.

In the study area, P_2O_5 reveals a sympathetic relationship with TiO_2 in the samples of lithomargic clay and laterites, but in the case of bauxite samples, an inverse relationship is noticed. Positive relationship in laterites and clay samples might be due to similar set of physico-chemical conditions, i.e. Eh (0.4-0.6) and pH (7.1-7.8) required for their precipitation (Israili, 1978).

V.3.1.7 : $\underline{SiO_2 \text{ vs. } Fe_2O_3}$:

There exists, both positive and negative relationship between SiO_2 and Al_2O_3 in the different

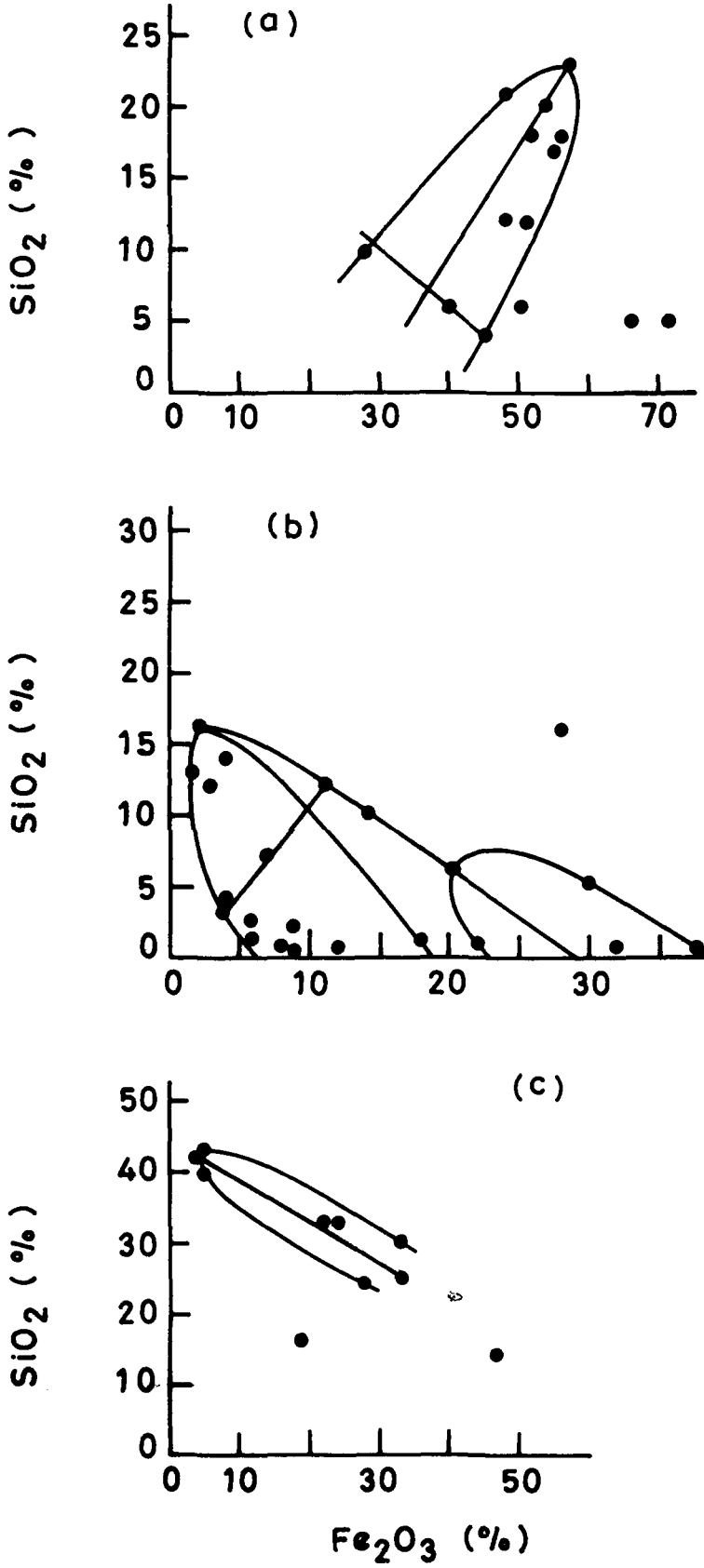


FIG. 22 CORRELATION DIAGRAM OF SiO_2 Vs. Fe_2O_3 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

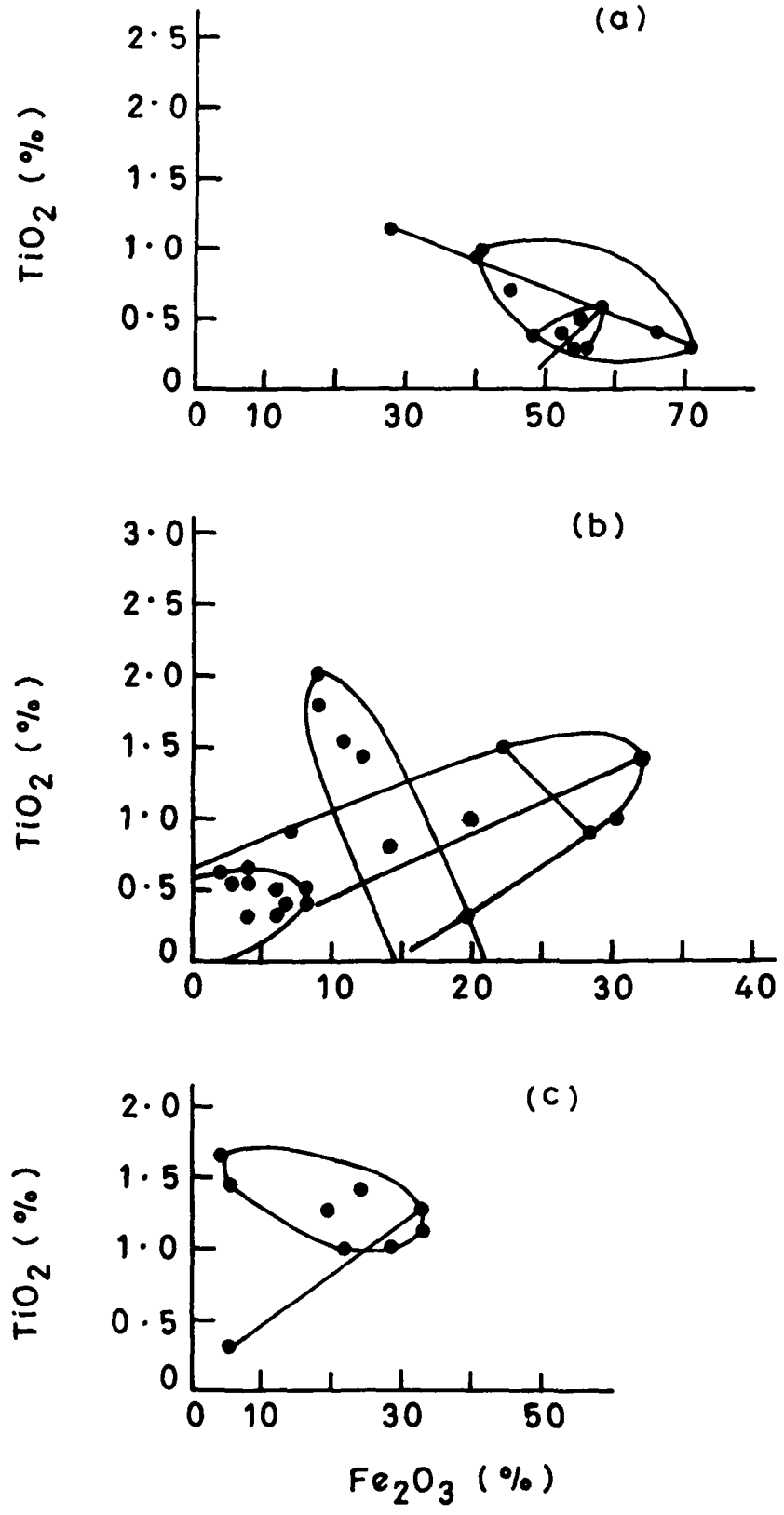


FIG. 23 CORRELATION DIAGRAM OF TiO_2 Vs. Fe_2O_3 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

zones of the bauxite profile (Figs. 22 a, b & c). In the clay zone, an antipathetic relationship is observed which is possibly due to alkaline pH and poor drainage conditions which are favourable for the fixation of silica.

In the bauxite zone, the relationship trend is perfectly negative because with the increase of Fe_2O_3, SiO_2 content decreases, while in the lateritic zone, the relationship appears to be positive because with the increase in Fe_2O_3 content, SiO_2 also increases. Increase in SiO_2 content in the upper-most zones may possibly be due to strong resilicification. Valeton (1972) pointed out that growth of vegetation (organic activities) is mainly responsible for silica fixation in the upper-most lateritic zone of the profile may hold good in the study area also.

V.3.1.8 : <u>TiO_2 vs. Fe_2O_3</u> :

In the zone of lithomargic clay, they show inverse relationship, except only, a few samples which reveal a positive relation. It may be possible due to the presence of high specific gravity and resistance to weathering of titanium bearing minerals.

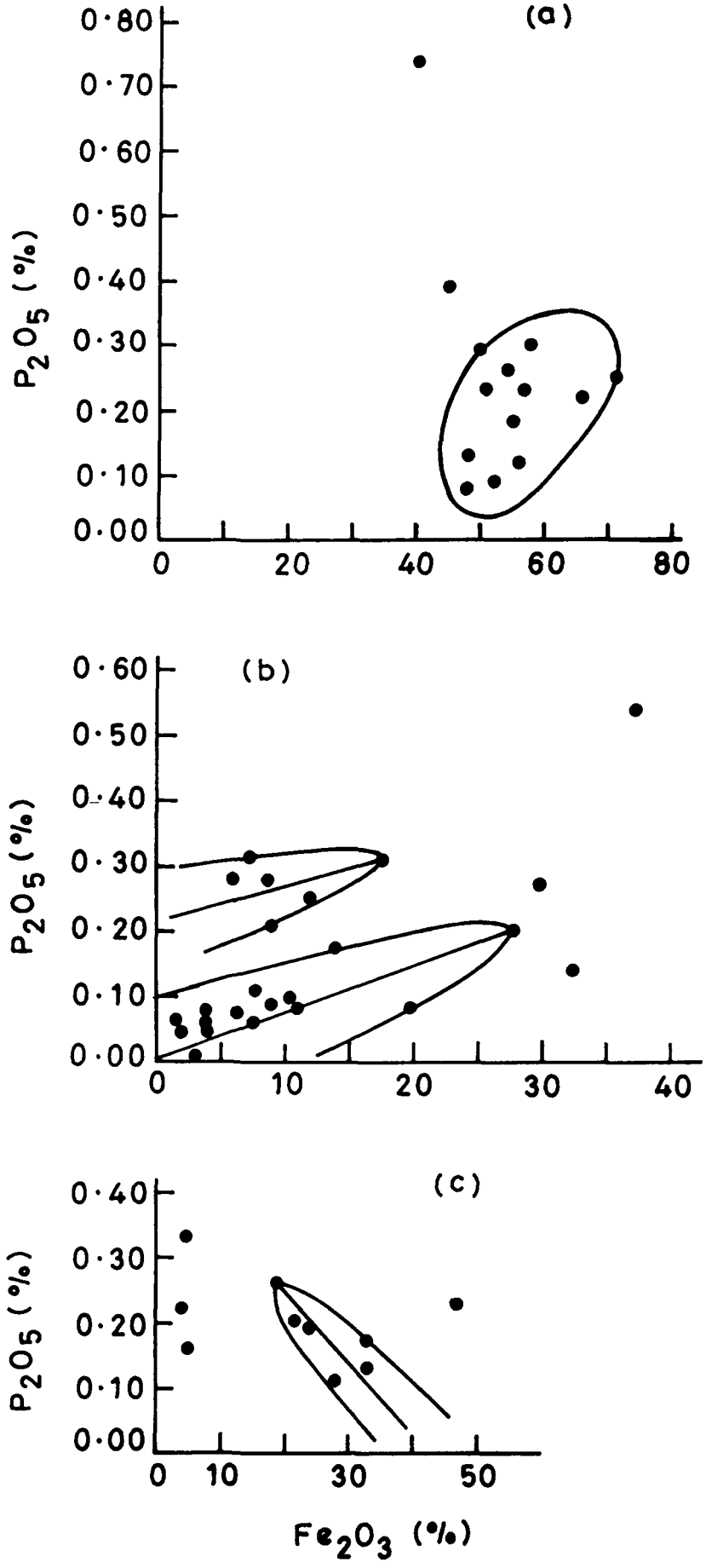


FIG.24 CORRELATION DIAGRAM OF P_2O_5 Vs. Fe_2O_3 IN
(a) LATERITE
(b) BAUXITE

In the bauxite zone, no definite trend has been observed a positive trend with Fe_2O_3, only in the bauxite samples, has been noticed which may possibly be due to the presence of more gibbsitic minerals (Loughman, et al., 1969) in them.

In the lateritic zone on the other, an inverse relationship has been noticed where with the increase in Fe_2O_3 content, TiO_2 tends to decrease. Few samples also show positive relationship between the two which may possibly be due to the effect of vegetal cover that leads to the relative enrichment of TiO_2 together with SiO_2 in the reworked zone (Krishna Rao and Borreswara Rao, 1976).

Graphic relationships between TiO_2 and Fe_2O_3 for bauxitic, lateritic and clay horizons have been shown separately (Figs. 23 a, b & c).

V.3.1.9 : $\underline{P_2O_5 \text{ vs. } Fe_2O_3}$:

In the lithomargic clay zone, P_2O_5 and Fe_2O_3 show inverse relationship where with the increase in Fe_2O_3 content P_2O_5 tends to decrease except only in

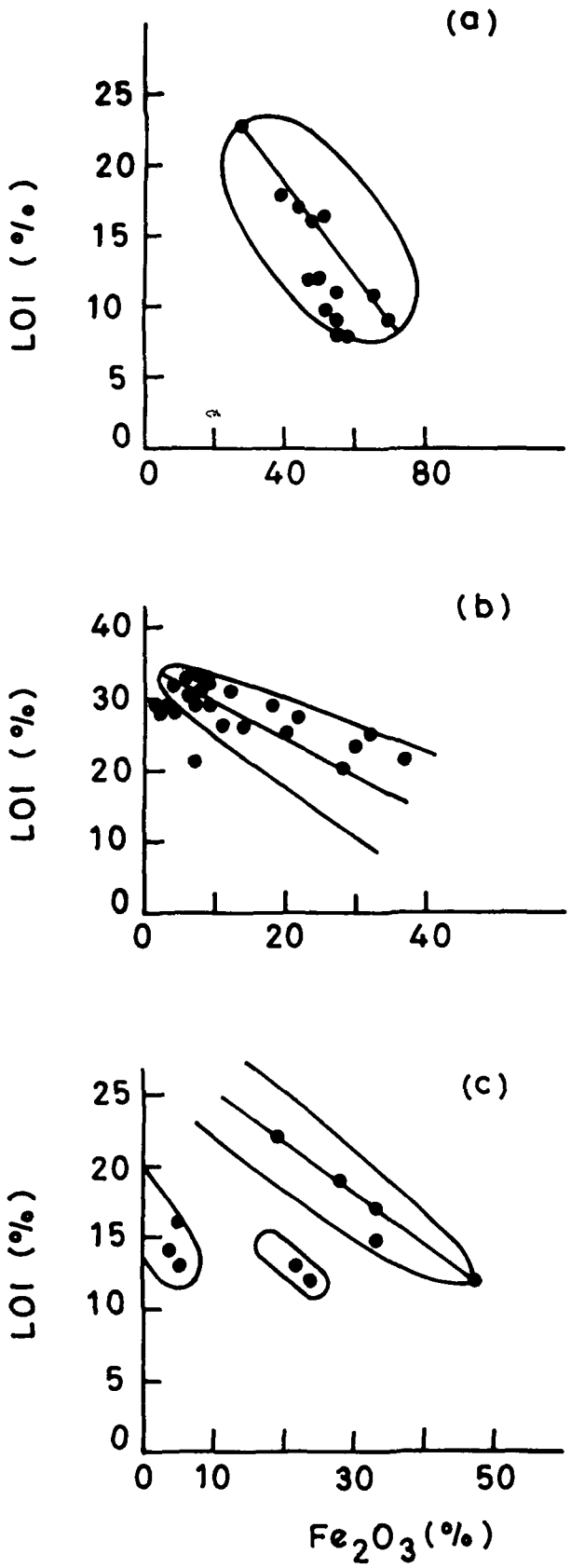


FIG. 25 CORRELATION DIAGRAM OF LOI Vs. Fe_2O_3 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

a few samples which show a weak positive relationship. It may possibly be due to the presence of apatite grains as resistates in them. Samples of the bauxite and laterite zones on the other, exhibit positive relationship where with the increase in Fe_2O_3 content, P_2O_5 also increase (Figs. 24 a, b, & c).

Goldschmidt (1937) stated that iron favours fixation of phosphorus under oxidizing conditions and therefore in the lateritic zone, it follows the same trend with the enrichment of iron.

V.3.1.10 : <u>LOI vs. Fe_2O_3</u> :

Figures-25 a, b & c, show negative or inverse relationship between LOI and Fe_2O_3 because with the increase in Fe_2O_3 content, LOI tends to decrease. Panicker et al. (1973), stated that LOI shows linear relationship with Al_2O_3, but the same does not hold true in the presence of goethite (iron hydroxide), which is one of the essential mineral in majority of rock samples of the lateritic profile.

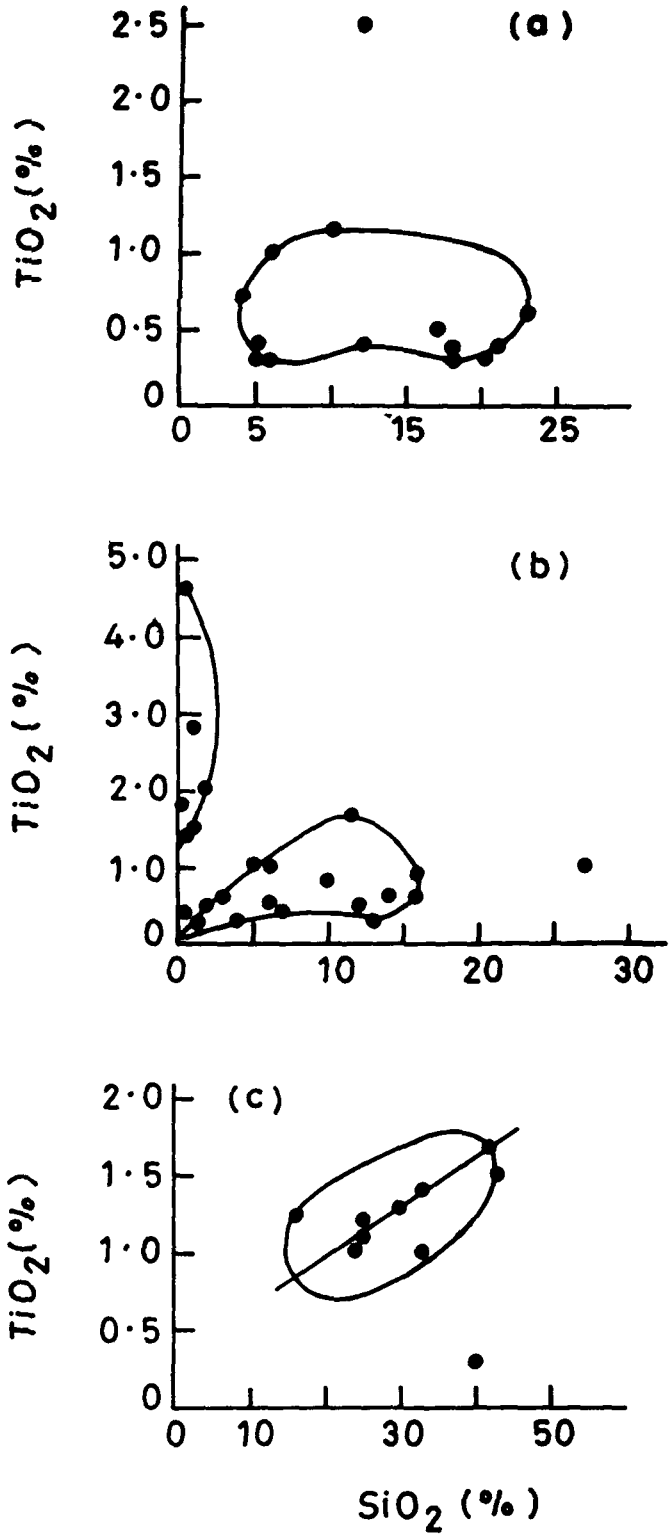


FIG. 26 CORRELATION DIAGRAM OF TiO_2 Vs. SiO_2 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

V.3.1.11 : $\underline{TiO_2 \text{ vs. } SiO_2}$:

TiO_2 maintains both positive as well as negative relationship with SiO_2 in the different zones of the bauxite profile (Figs. 26 a, b & c).

In the zone of lithomargic clay a sympathetic relationship has been observed where both tends to increase/decrease at the expense of one another. Positive relationship of TiO_2 with SiO_2 in this zone may possibly be due to its high specific gravity, less mobility and resistance to weathering. In the major portion of the bauxite zone, both show positive relationship. Krishna Rao and Borreswara Rao (1976) mentioned that organic activities or vegetation may create such an environment which leads to relative enrichment of SiO_2 and TiO_2. As stated earlier, the same factor might have been responsible in the present study also.

In the upper-most lateritic zone no definite pattern of relationship is observed.

V.3.1.12 : $\underline{Al_2O_3/Fe_2O_3 \text{ vs. } TiO_2}$:

The ratio between Al_2O_3 and Fe_2O_3 were plotted against TiO_2 values for different zones of the profile, to know their trend of correlation (Figs. 27 a, b & c).

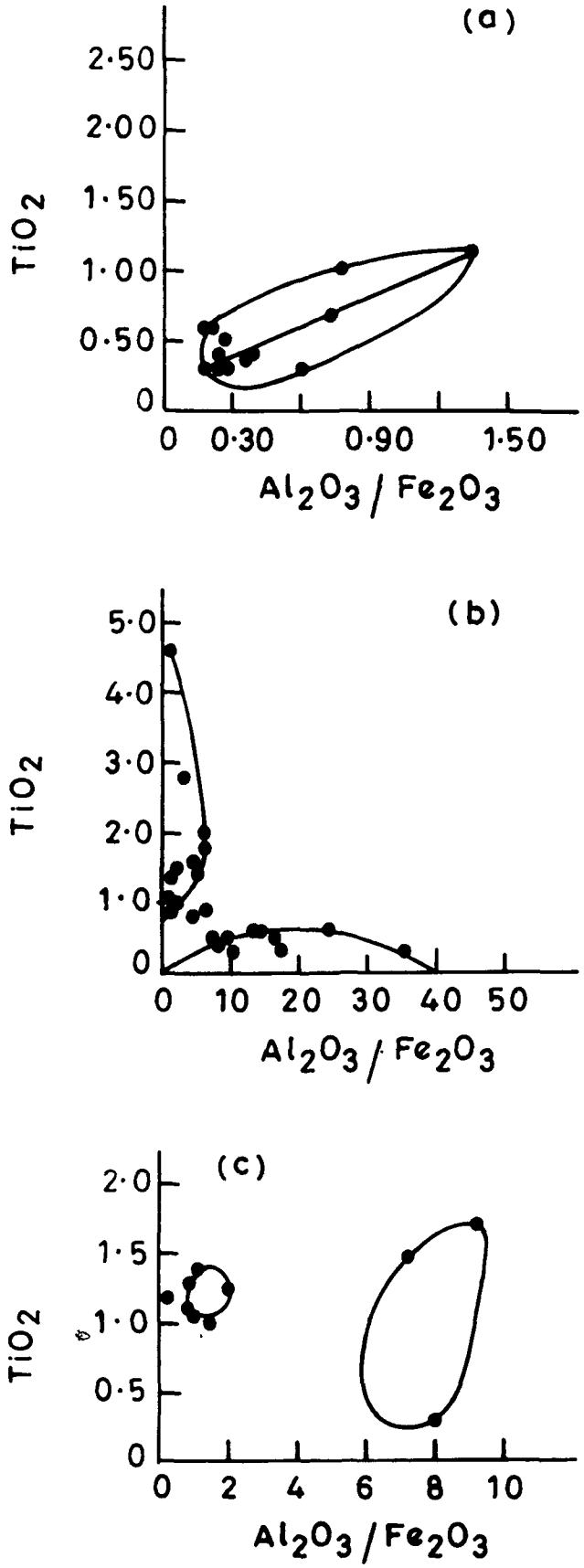


FIG. 27 CORRELATION DIAGRAM OF TiO_2 Vs. Al_2O_3/Fe_2O_3 IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

A positive and significant relationship in the zones of lithomargic clay and laterites has been noticed, because in these zones Al_2O_3/Fe_2O_3 ratio is not much higher as compared to that of the bauxite zone, in which a random relationship is found between these constituents. This is due to the fact that Al_2O_3 and Fe_2O_3 require almost different set of physico-chemical conditions for their fixation within the same zone.

V.3.1.13 : Fe_2O_3 vs. total ($Al_2O_3 + TiO_2$) :

Fe_2O_3 shows a weakly negative correlation with ($Al_2O_3+TiO_2$) throughout the bauxite profile. In the different zones, the slope line shows variable steepness. It is very much steeper in the bauxite zone as compared to the lithomargic and lateritic zones. The plotting shows a gradual increasing concentration of $Al_2O_3+TiO_2$. This type of trend also reveals that precipitation of $Al_2O_3+TiO_2$ and Fe_2O_3 requires different sets of physico-chemical conditions. The absence of positive relationship between these oxides throughout the bauxite profile, proves the removal of one by another.

Correlations between these elements were shown separately for the different zones of the profile (Figs. 28 a, b & c).

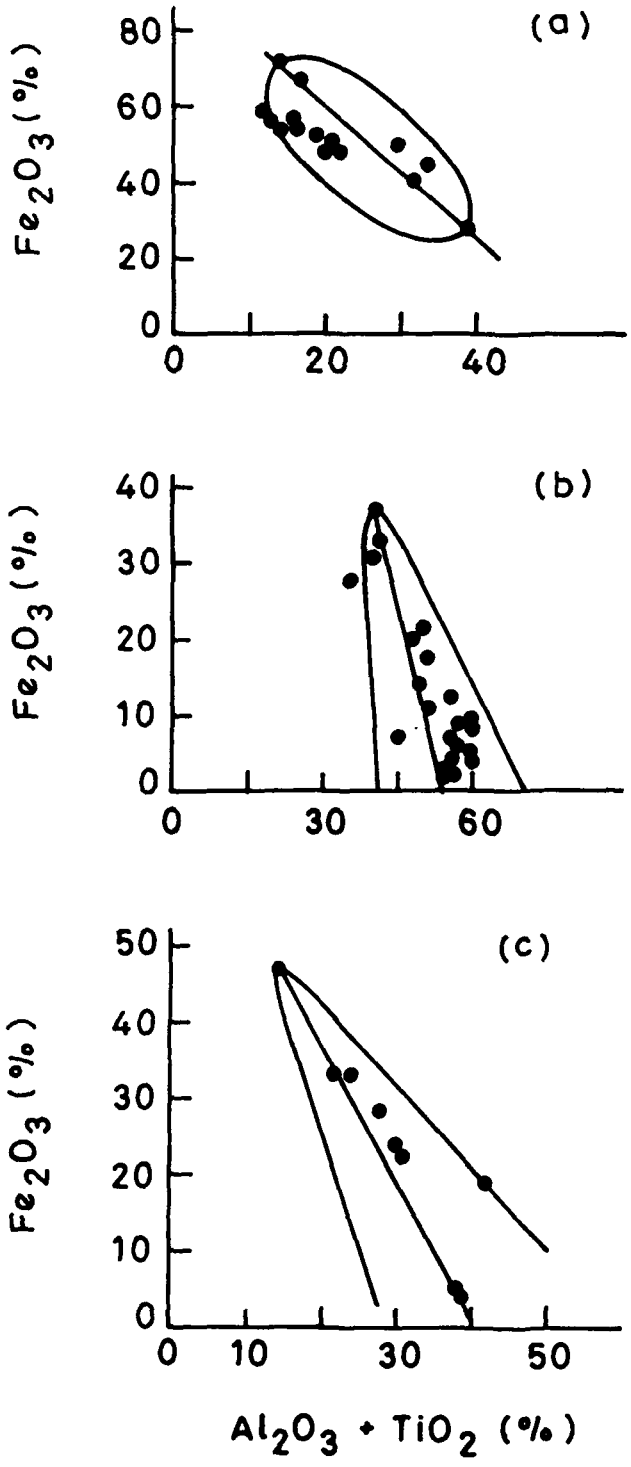


FIG. 28 CORRELATION DIAGRAM OF Fe_2O_3 Vs. $Al_2O_3 + TiO_2$ IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

V.3.1.14 : SiO_2 vs. total (Al_2O_3+TiO_2) :

The correlation between these elements varies in the different zones (Figs. 29 a, b & c). In the zone of lithomargic clay a positive correlation exists between SiO_2 and total (Al_2O_3+TiO_2). A gradual increase in Al_2O_3+TiO_2 contents with the increasing concentration of SiO_2 has been observed. In this zone poor drainage and high pH favours their fixation while in the upper, laterite and bauxite zones the relationship trend reverses and there exists a negative correlation between these constituents. With increase in Al_2O_3+TiO_2 content, silica concentration decreases gradually because of suitable drainage and change in physico-chemical conditions, especially Eh-pH in these zones.

V.3.1.15 : Petrochemical Fields & Trends :

In the present study, an attempt has been made to known the petrochemical fields, by taking into consideration, the major constituents viz., Al_2O_3, Fe_2O_3, SiO_2 and TiO_2, etc.

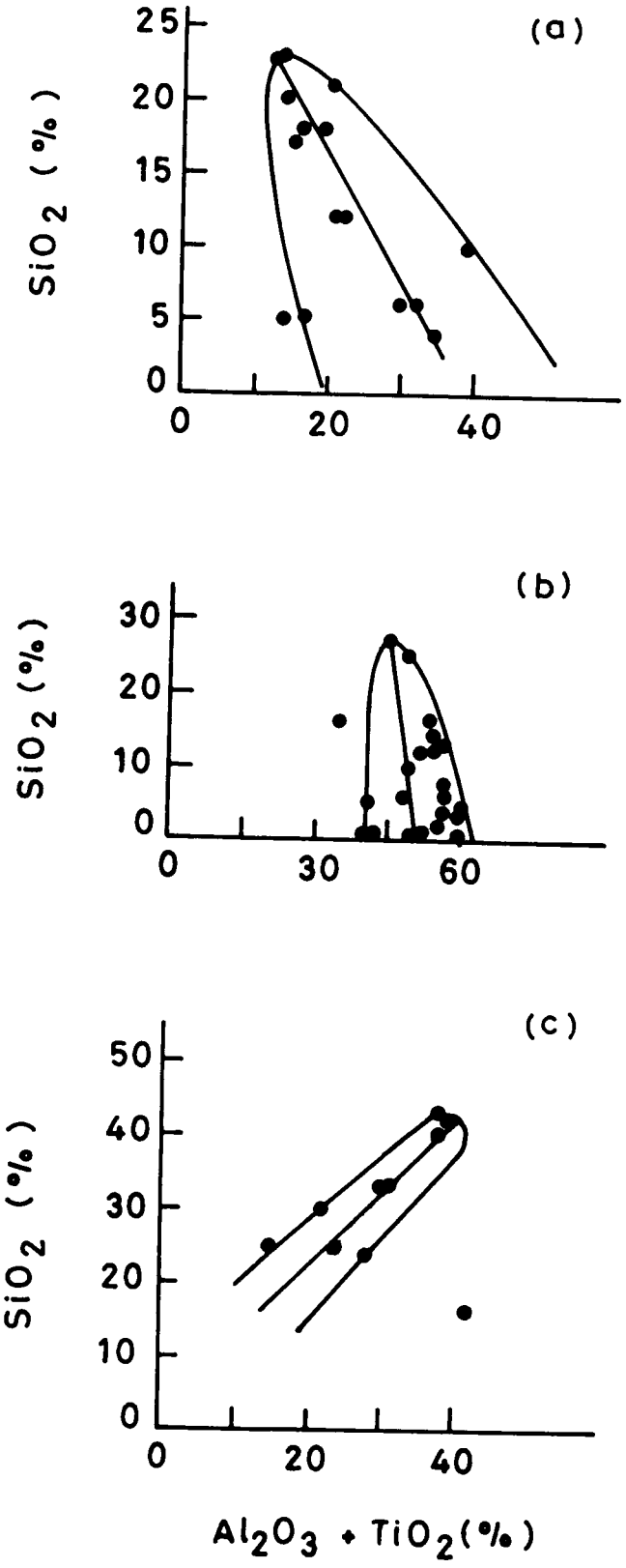


FIG. 29 CORRELATION DIAGRAM OF SiO_2 Vs. $Al_2O_3 + TiO_2$ IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

Weight percentages of the oxides (SiO_2, Al_2O_3, Fe_2O_3) and (SiO_2, Al_2O_3+TiO_2, Fe_2O_3) were recalculated, to study the petrochemical fields and trends of enrichment or depletion in the bauxite profile as compared to the parent rocks. The data obtained by recalculation were plotted on a triangular graph paper following the techniques adopted by Green and Poldervaart (1958), Valeton (1972) and Rahman (1978).

As mentioned earlier, the bauxite deposits of Shevaroy hills are characterized by highly variable nature of bauxite because of wide range in physico-chemical conditions required for the precipitation. The physico-chemical factors (Eh-pH) mainly influence the precipitation of Al_2O_3, Fe_2O_3, SiO_2 and TiO_2 rather than CaO, MgO, Na_2O and K_2O. An attempt has therefore been made to understand the role of physico-chemical factors in the depletion or enrichment of the major constituents during the process of bauxitization.

V.3.1.16 : <u>SiO_2-Al_2O_3-Fe_2O_3 Diagram</u> :

The total 100 weight percentages values of SiO_2-Al_2O_3-Fe_2O_3 were plotted on the triangular diagram to know the trend of enrichment and/or depletion in the

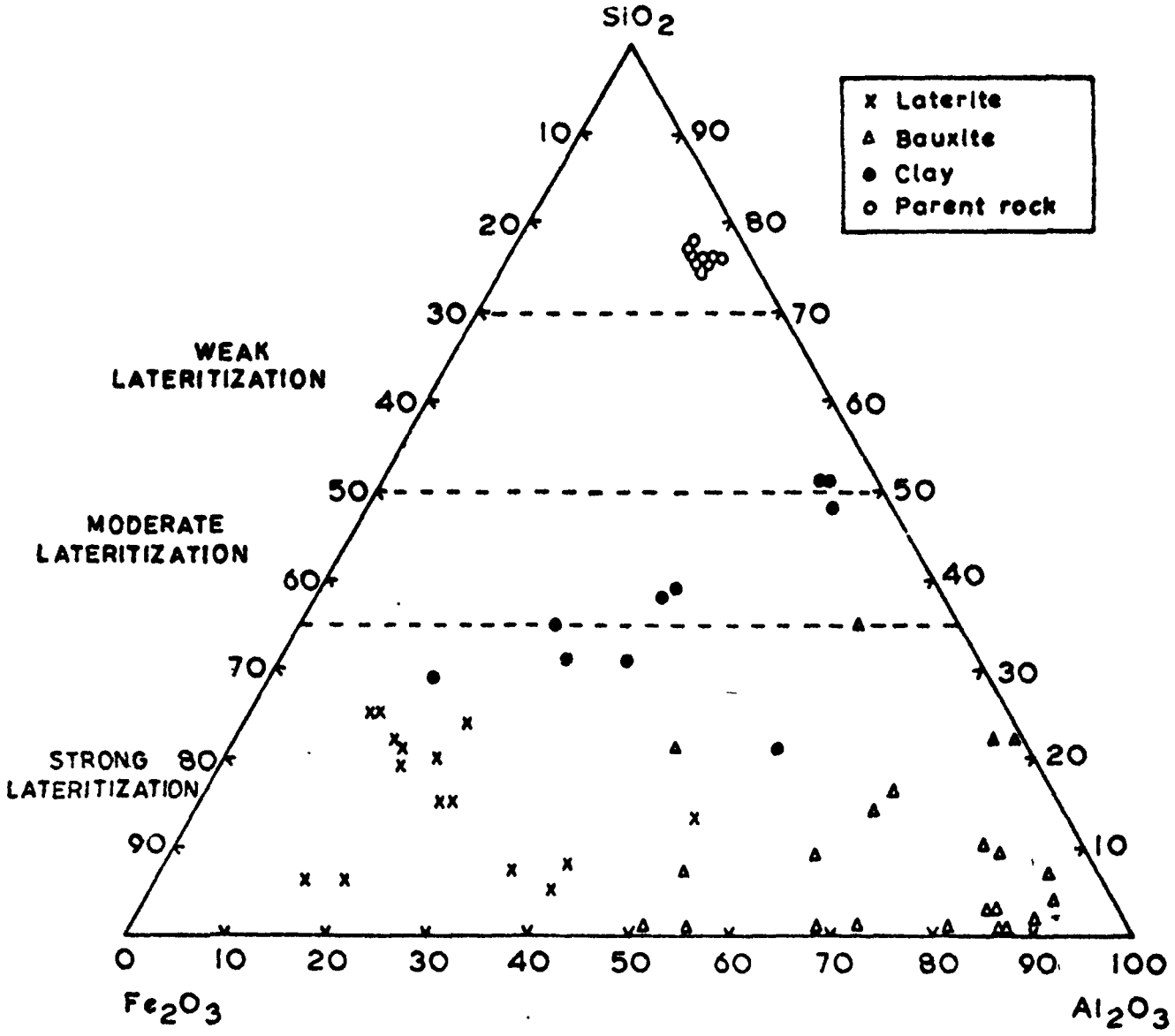


FIG. 30 REPRESENTS THE SiO_2 - Al_2O_3 - Fe_2O_3 TRIANGULAR DIAGRAM OF SHEVAROY BAUXITIC PROFILE AND DIFFERENT STAGES OF LATERITIZATION

bauxite profile as compared to the source rocks of Shevaroy hills. The parameters of country rocks, taken into account include SiO_2 (77.58%), Al_2O_3 (19.93%) and Fe_2O_3 up to 6.36%, hence most of the points lie in the SiO_2 field. On the other hand from lithomargic clay zone upwards to laterite zone, a depletion in SiO_2 content and enrichment in Fe_2O_3 and Al_2O_3 in varying proportions has been noticed.

Observed contents in the lithomargic zone include SiO_2 (51.04%), Al_2O_3 (35.45%) and Fe_2O_3 up to 25.81%. In the bauxite zone, the observed Al_2O_3 content reaches up to 89.51%, Fe_2O_3 35.34% and SiO_2 17.69%. In the laterite zone, the maximum constituent of Fe_2O_3 reaches up to 79.08% which dominates much over the Al_2O_3 and SiO_2 contents. Most of the points therefore, lie in the Al_2O_3 and Fe_2O_3 field respectively. It is therefore inferred that country rock has been subjected by the intense chemical weathering, resulting in the desilicification and enrichment of Al_2O_3, Fe_2O_3 under the different sets of physico-chemical conditions (Fig. 30, Table-VIII).

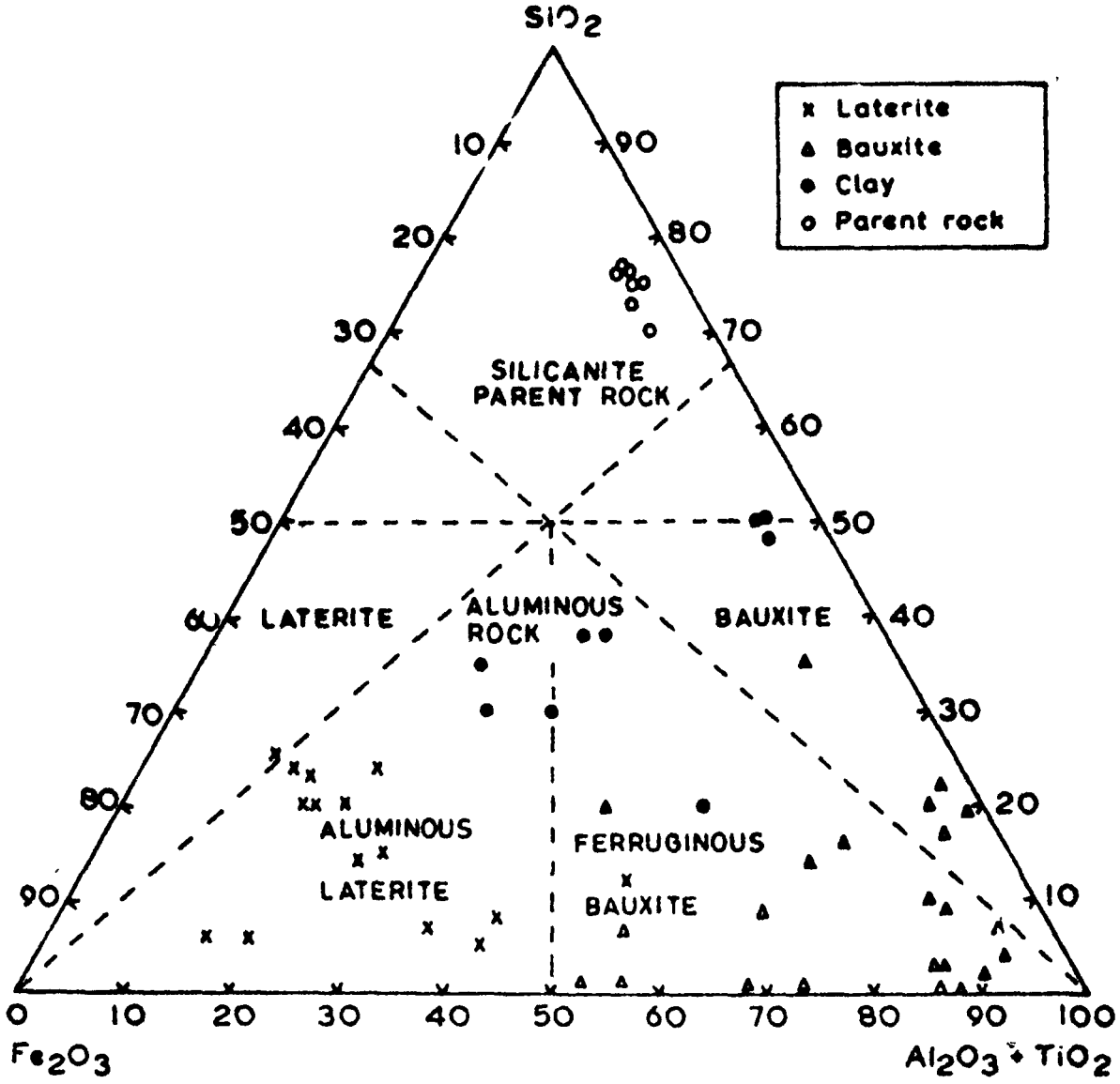


FIG. 31. REPRESENTS THE SiO_2 - Al_2O_3 + TiO_2 - Fe_2O_3 TRIANGULAR DIAGRAM AND CLASSIFICATION OF SHEVAROY BAUXITE

V.3.1.17 : SiO_2-(Al_2O_3+TiO_2)-Fe_2O_3 Diagram :

Almost similar fields and trends were obtained after plotting these parameters. It is similar to the above, except having an addition of TiO_2 in the Al_2O_3 content. As discussed earlier, that Al_2O_3 and TiO_2 behave alike during the weathering cycle, hence these constituents have been added together. The weight percentage concentration of the constituents will be slightly modified due to the addition of TiO_2 with Al_2O_3. Weight percentages of total Al_2O_3+TiO_2 reaches up to 89.57% in the bauxites and 41.25% in the laterites, while in the lithomargic zone, it is 37.64%. Most of the points show a widespread trend in between Fe_2O_3 and Al_2O_3+TiO_2 fields. Parent rock composition falls towards the SiO_2 apex of the triangle.

It thus reveals the nature of conversion of the parent rock into the bauxite ore body, under the influence of physico-chemical conditions. At the same time, it could also be inferred that the constituent which was removed in larger amount from the country rock was silica, while Al_2O_3 and Fe_2O_3 were the major constituents enriched in the profile, although enrichment trend of TiO_2 was also perfectly similar to that of the Al_2O_3, but its meagre concentration in the source rocks could not make it a significant constituent (Fig. 31).

V.4 : SYNTHESIS OF BAUXITES :

From the above discussion, it could be inferred that the following factors are responsible in the formation of the bauxites and other rock units of the bauxitic profile.

V.4.1 : ROLE OF Eh-pH :

These two chemical properties of water which influences most of the different chemical reactions produced during the process of bauxitization, are pH and Eh. Each one of these has an influence on the stability of minerals or their ion or component compounds and in the distribution of the chemical constituents during the process of bauxitization.

Specific significance of the pH values is in the variation of physico-chemical environment of the different zones in the profile that influenced the weathering of the bed rock, solution and transport or migration of the chemical constituents, and also in the fixation of the various residual constituents during the lateritic weathering.

The distribution of Al, Fe and their associated major and minor elements in the bauxite profile depends upon the pH. The pH in turn depends upon the capillary water which acts as a universal solvent.

The changes in the pH of the solution acting on the rocks depend upon a number of factors :-

1. Nature of the rocks (due to abrasion pH).
2. Influence of vegetation and organic matter.
3. Temperature and presence of other mineral substance.
4. Surface and subsurface drainage conditions.

For instance, in the mafic rocks, pH will be more alkaline while it is neutral to slightly acidic in the intermediate and garnetiferous rocks. Valeton (1972) noted that comparatively higher pH (7.8 and 7.6) of water from basaltic region, is the result of their association with a basic body having Ca, Mg and alkali contents and the fast rate of release of these components due to speedy break down of the parent material. In the present investigation, more commonly the parent rock is acidic in nature, its Ca, Mg and alkali contents are lower than that of basic rocks, still lower is the rate

of release of the cations due to poor rate of break down of the parent material. Ultimate product of weathering in the present case will be kaolinite as a dominant residual mineral. It adsorbs H^+ ions depending on its cation exchange capacity and behaves as an acid; because the degree of acidity depends on the cation exchange capacity of the residual minerals. In this connection (Loughman, 1969) mentioned that it also renders its environment to assume a lower pH.

Britton (1965) determined the pH of hydrolysis of certain major elements which is given below :-

Elements	pH
Fe^{3+}	2.0
Fe^{2+}	5.5
Al^{3+}	4.0
Mg^{2+}	10.5

This indicates that Fe^{2+} will be in solution as pH reaches 2.0 and Fe^{3+} ions are likely to be precipitated at this pH range.

Fortescue (1979) observed the behaviour of silicon and aluminium with respect to change in pH and suggested that SiO_2 would increase in mobility with increasing alkalinity, and Al_2O_3 would be insoluble under very alkaline conditions. It should be noted that from pH-5 to pH-9, the solubility of silicon is relatively high but aluminium is relatively insoluble.

Mason (1966) predicted that ground water pH offered an explanation for the formation of particular clay minerals from the same parent rock under different physico-chemical environments. He predicted that under alkaline conditions (ph 8-9), the relative abundance of silica in solution with respect to aluminium would favour the formation of montmorillonite clay, whereas under more acid conditions, kaolinite would form.

Gardner (1970), Ulrich (1971) and Norton (1973) observed that Eh and pH affects the concentration of Al_2O_3, Fe_2O_3 and SiO_2 along the profile. Other workers also opined that the concentration of either iron hyrodixes or aluminium hydroxides depends on the pH of the environment and drainage conditions.

Norton (1973) applied Eh-pH diagrams to solve this problem and he was able to explain more accurately the limiting conditions for the formation of laterite

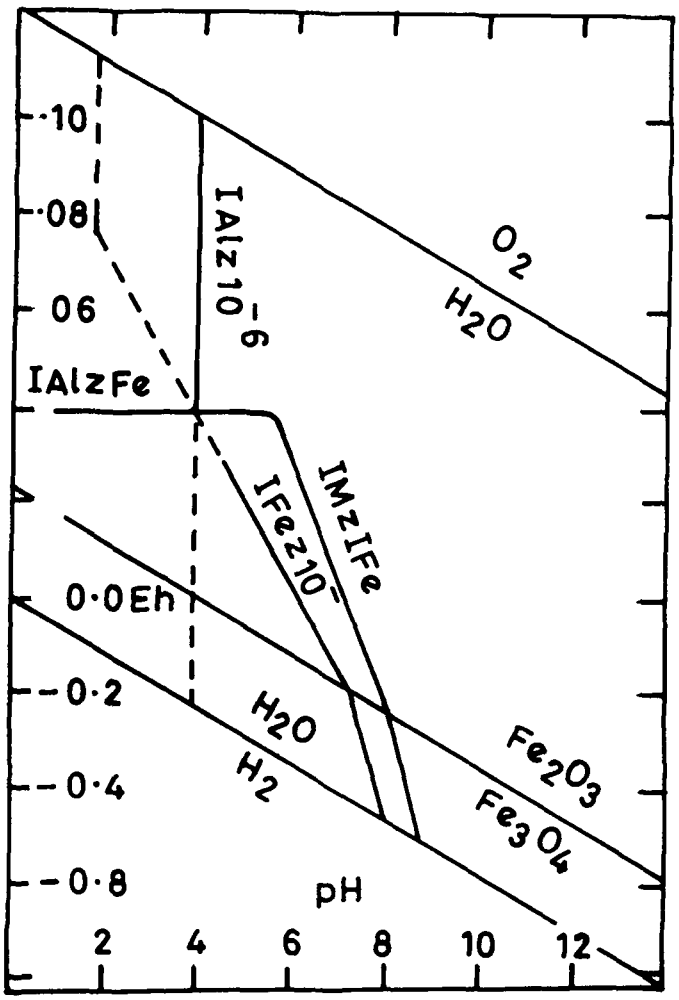


FIG. 32 SIMPLIFIED DIAGRAM SHOWING SOLUBILITY RELATIONSHIP AMONG HEMATITE, MAGNETITE, GIBBSITE AND WATER (NORTON, 1973)

or bauxite and the accompanying enrichment of Mn, Co and Ni etc.

From the Eh-pH diagram (Fig. 32) it could be inferred that solution with pH below 3.5 will mobilise Al and at high Eh, Fe is residually enriched, whereas at low pH and Eh, Fe is also mobilised. At higher pH the Eh-pH diagram may be divided into two areas by a line of equal solubility for Al and Fe. Below this line, Fe minerals are more soluble. Another line, setting limits on mobility, also divides the Eh-pH diagram into two areas. At higher Eh and/or pH, both Al and Fe are immobile. At lower pH (but above 3.5) and/or Eh bauxitization may occur depending on whether the Eh falls below or above the insolubility line respectively.

Gibbsite or hydroxides of aluminium preferentially leached out by solutions having pH about 3.8 and Eh above 0.5 m.v. Goethite and hematite are preponderantly dissolved by solution having pH about 4.2 and Eh below 0.3 m.v., due to dissolution of considerable amounts of either gibbsite or goethite (Al or Fe hydroxides).

Danse (1959), Grubb (1963), Haung and Keller (1971), Valeton (1972), and Krishna Rao and Borreswara Rao (1976) stated that growth of vegetation and presence of humid acids, affects the pH of the solution which in turn leads to relative enrichment of SiO_2 and TiO_2 in

the reworked zone and would facilitate the migration of Fe and Al. The same mechanism of plant action on soil in cation exchange, has also been explicity described by Jenny and Overstreet (1939), Williams and Coleman (1950), Graham and Baker (1951); and Keller and Frederickson (1952).

Alumina rich horizon would be formed, provided the pH of ground water remains above 4 and a low Eh would be necessary to activise the transport of iron with residual enrichment of alumina (Pickering, 1962 and Paterson, 1971).

Various constituents in surface and subsurface water also affects the nature of pH. It is well observed that there is a marked variation in the surface and subsurface pH values due to abrasion pH of the constituent minerals and due to release of alkalies and alkaline earth elements into solution. It is therefore, believed that near the surface, pH is slightly on alkaline side, while it is acidic at the surface contact, because after the first stage of weathering during the clay formation, alkalies are removed, makes the water of alkaline nature which in turn favours the enrichment of aluminium or iron hydroxides.

On the contrary, Banerjee (1972) stated that alkaline conditions developed by the primary silicates, with the water molecules in contact, enables removal of silica and magnesia and stabilizes the iron and nickel cation. Low alkaline, neutral or slightly acidic abrasion pH developed in the oxide and hydroxide rich laterite may lead to the removal of already concentrated iron and nickel.

As already mentioned that the Eh-pH conditions (i.e. low Eh and neutral pH) for the enrichment of alumina, still poses a problem for the effective removal of ferric iron, since it is soluble only in strong acidic environment. To solve the problem, Harder and Bateson (1962) and Shapiro (1964), proposed that organic complexes act as chief carriers of ferric iron. Goldschmidt (1937) also emphasized the role of bacteria in the modification of physico-chemical environment and he stated that iron would be precipitated under the oxidizing conditions while reducing environment brings it into solution. It is further believed that the essential factor for the enrichment of iron during the process of lateritization, is the high oxidation potential (Eh) of the solution that decompose the bed rock. Nearly all Fe^{2+} minerals were found to be oxidised to Fe^{3+} in the upper-most zone of the Shevaroy bauxite profile.

Good drainage conditions near the surface favour the formation of hydroxides of alumina, while the acidic conditions and sluggish drainage below the surficial zone, especially at the contact of ore body with the parent rock, facilitate the formation of kaolinite or clay zone.

Sahoo, et al. (1980) noted that efficient leaching of MgO and its subsequent removal is favoured by a mildly acidic environment.

From the foregoing discussion, it has been cleared that the variations in pH values decide the concentration of either hydroxides of aluminium,iron or formation of kaolinite during the process of bauxitization.

During the first stage of chemical weathering, alkalies and alkaline earths (Na, K, Ca, Mg) are removed, make the solution alkaline, further changes in the environment make the solution acidic or neutral. Acid conditions (low pH) generally promotes the solution of iron, alkaline conditions (high pH) promotes the precipitation of iron and low to intermediate pH and low Eh favours the concentration of alumina.

V.4.2 : ROLE OF TITANIUM :

Titanium is the most abundant trace element which

is enriched in bauxites and generally the concentration of TiO_2 in laterites and bauxites of the present day ranges from 0.5 to 33% (Katsura, et al., 1962). However, in the bauxites of Shevaroy hills, it ranges from 0.27% to 4.60%, which is comparatively less if compared with the bauxites derived from Deccan-basalts, having more titanium bearing minerals. Thus, it is therefore inferred that the neo-mineralization or concentration of titanium minerals in the bauxites depends on the quantities of titanium available in the host rocks.

Since titanium is dissolved and precipitated under similar conditions to aluminium, hence its role could be considered as one of the important factors in the enrichment of aluminium or in the genesis of bauxites. Ilmenite and titanomagnetite are the main carriers of titanium in the bauxites.

During the process of lateritization/bauxitization most of the silicate minerals get hydrolyzed in an aqueous medium where surface and ground water are freely available, released ions which are adsorbed by clay minerals, create an acidic environment. However, the titanium minerals are resistant enough to weathering, but advance stage of lateritization/bauxitization, under the acidic environment dissolves titanium and transported it as Ti^{4+}, which finally reprecipitated as anatase - a polymorph of titanium

mostly found in the laterites/bauxites. This process explains the reconstruction phenomenon under aqueous medium (Frederickson, 1948). Hydration and dehydration processes involved in the neo-mineralization of anatase (TiO_2) is illustrated by Rahman (1978) as :-

$$Ti(OH)_2 \longrightarrow TiO_2^{++} + 2OH \longrightarrow TiO_2 + H_2O$$

During weathering Ti and Fe migrate separately but follows the trend of aluminium, because of the difference in ionic charges, created by Ti^{4+} ions.

According to Rankama and Sahama (1949), due to hydrolysis, the zone of lateritization becomes partially a zone of dispersion colloidal system, which contains negatively charged SiO_2 and $Fe(OH)_3$ and positively charged $Al(OH)_3$ (though in alkaline medium $Al(OH)_3$ may be negatively charged). This explains the whole mechanism involved in reversing $Al(OH)_3$ charge by Ti^{4+} ions and uniform trend of precipitation. It is also in conformity with Valeton (1972) who stated that titanium enriches with aluminium in most laterites, indicating transport of Fe^{2+} and precipitation of $Fe(OH)_2$. It could therefore be inferred that bauxite formation or enrichment of aluminium is dependent on titanium i.e. the precipitation or migration of $Fe(OH)_3$ and $Al(OH)_3$ is controlled by the

presence of Ti^{4+} ions besides other governing factors.

Another aspect regarding the precipitation and removal of $Al(OH)_3$ and $Fe(OH)_3$ is the Zeta potential, proposed by Glasstone (1962); according to him Ti^{4+} bring down the zeta potential of $Fe(OH)_3$ sol and cause its flocculation or migration from the colloidal system.

Finally, it could be concluded that the bauxite of the present area as mentioned above, contains less concentration of titanium, because of its poor concentration in the underlying rocks, which in turn affects the formation of good quality bauxites. In the weathering zone, iron instead of migration, precipitated as $Fe(OH)_2$, resulted in lateritic bauxites, which is the case of Shevaroy bauxite that are lateritic in nature.

Based on major oxides geochemistry and their trend of correlation, the following conclusions could be drawn :-

1. SiO_2 decreases upwards from bed rock towards the bauxite zone. In the laterite zone, resilicification was favoured by vegetation cover and other organic activities.

2. Al_2O_3 and TiO_2 increases upwards from lithomargic zone to the bauxite zone and further their concentration diminishes in the upper-most laterite zone.

3. Fe_2O_3 increases upwards and reaches its maximum in the laterite zone.

4. CaO, MgO, Na_2O and K_2O are removed in solution during the first stage of weathering, and their continuous depletion was observed throughout the profile. In the lithomargic zone comparatively they show slight enrichment, possibly due to poor drainage and adsorbent property of clay minerals.

5. P_2O_5 does not show any significant trend of either depletion or concentration except only in a few samples, its concentration reaches up to 28.71% in the laterite zone, where it follows the trend of Fe_2O_3 concentration, which may be due to the action of phosphatic meteoric water on the predeposited laterites or bauxites.

6. Al_2O_3 maintains sympathetic relationship with TiO_2 because of similarity in chemical characters and in physico-chemical environment, required for their precipitation.

7. The antipathetic relationship of Al_2O_3 with Fe_2O_3 and SiO_2 indicate that their concentration is favoured by different set of physico-chemical environment. They remove each other in their favourable environment of precipitation.

8. An antipathetic relationship has been found between Al_2O_3, Fe_2O_3 and TiO_2 with SiO_2, throughout the profile, indicate that Eh-pH required for the precipitation of Al_2O_3, Fe_2O_3 and TiO_2 was quite different than that of SiO_2 precipitation. Few samples show almost equal proportion of Al_2O_3 and Fe_2O_3, indicating thereby a wide range of pH and Eh that favoured precipitation or removal of both Al_2O_3 and Fe_2O_3.

9. The gradational and progressive chemical changes i.e. enrichment of Al_2O_3, Fe_2O_3 and TiO_2 with the depletion in SiO_2 content (the concentration of Fe_2O_3 is lesser than Al_2O_3) from charnockites through lithomargic clay to bauxites indicates residual or in situ weathering of underlying charnockites, under the influence of suitable physico-chemical environment.

CHAPTER - VI

GEO-CHEMISTRY OF TRACE-METALS

CHAPTER - VI

GEOCHEMISTRY OF TRACE METALS

VI.1 : GENERAL STATEMENT :

Knowledge of trace metals and their significance have been known since the beginning of the 20th Century. Washington (1913) probably was the first to study the distribution of trace metals, did not relate only to rock types but also to the major elements constituting the rocks. Vogt (1918) and Buddington (1933) studied critically the distribution pattern of trace metals. Goldschmidt (1954) proposed a major concept of trace metal geochemistry is that there is the tendency for certain minor elements or trace elements to follow major elements, that are similar to them in radius and bond type.

On the most general level, certain minor elements will substitute quantitatively for one major rock forming elements in preference to other depending on the prevailing physico-chemical conditions (Goldschmidt, 1937; Rankama and Sahama, 1949; Gordon and Murata, 1952; Butler, 1953, 1954; Adams and Richardson, 1960; Short, 1961; Hotz, 1964; Wolfenden, 1965; Chowdhary, et al., 1965; Khalighi, 1968;

Bardossy and Panto, 1973; Valeton, 1972; Banerjee, 1975 and Jagannatha Rao and Krishna Murty, 1980).

Banerjee (1975) carried out a reconnaissance survey of the distribution of some trace metals in Indian bauxites and tried to reveal their source, in certain mineral groups. He also pointed out that the extent of a bauxite deposit could be anticipated from the degree of variance of the trace elements.

Using the trace elements distribution and their relation with the major elements, it is possible to identify every stage of weathering and leaching cycle of lateritization process. Differential concentration of trace elements is noticed with the characteristic mineral assemblages in each unit from base to upwards.

In order to achieve the objectives related to the geochemical behaviour of major and trace elements and their variations trend in the bauxite profile about 20 trace elements viz., Li, Mn, Cu, Pb, Zn, Ni, Co, Ba, Sr, Sn, Mo, Cr, In, Ge, Be, Zr, V, Y, Ga were analysed. A few of them could not be determined properly because of their concentration below the detectable limit in the samples analyzed. Obtained results of the trace elements are presented in Table-X. Figure-33(a, b, c & d)show the distribution of trace metals in various zones of the bauxite profile and associated parent rock.

Comparative concentration of trace metals in other bauxite deposits of the country is given in Table-XI.

TABLE - XI : Comparison of trace metals concentration (in ppm) in the Shevaroy bauxite deposits with the other bauxite deposits.

Elements	Shevaroy bauxites	East coast bauxite (Kalsotra & Prasad, 1980)	Amarkantak bauxite (Kalsotra & Prasad, 1980)	Maharashtra state (Sahasrabudhe, 1981)
Ga	20	27	86	5
Cu	5	<5	104	140
Ba	<50	<1	95	35
Sr	<100	<5	86	-
Ni	20	<5	23	69
Co	<10	<5	<10	28
Cr	490	206	575	260
Zr	390	145	465	281
V	290	181	1191	477

In the study area, the relative enrichment or depletion of the elements have been worked out by assuming the basement rock as to have the original composition (Table-XII).

VI.2 : DISTRIBUTION OF TRACE METALS :

VI.2.1 : GALLIUM (Ga) :

Gallium was discovered by Boisbraudran in 1875 who named it in honour of Gallia, the Latin name of France. Goldschmidt (1937) stated its resemblance with Al^{3+} in various ways, most strikingly in the properties of the oxide, Ga_2O_3.

Banerjee (1975) stated that in charnockites, plagioclase feldspar is the chief carrier of gallium.

In the Shevaroy bauxite samples its concentration ranges from 10 to 30 ppm, as compared to the parent rock concentration having an average of 5 to 7 ppm of Ga. It shows an appreciable enrichment, particularly in the bauxite zone where it reaches up to a maximum 30 ppm. (Table-X).

Low gallium content of these bauxite samples indicates, low abundance of gallium in the parent rocks is in accordance with the results of east coast bauxites having 10-20 ppm Ga. Because of its closeness in ionic radii with Al^{3+} and Fe^{3+}, it does not occur as individual mineral but is commonly found camouflaged in various aluminium minerals (Goldschmidt, 1937; Shaw, 1957 and Chowdhary, et al., 1965).

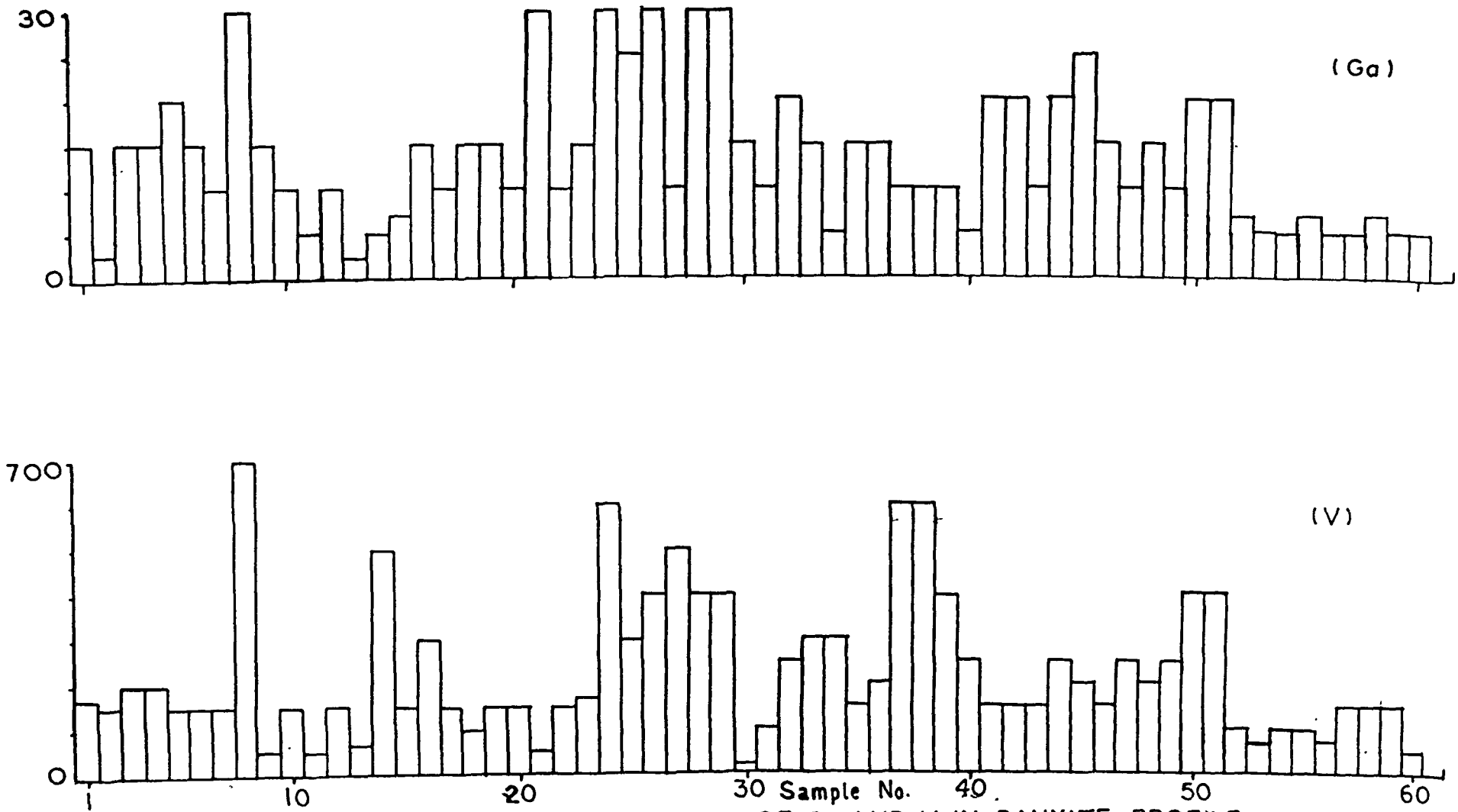


FIG. 33(a) HISTOGRAMS SHOWING DISTRIBUTION OF Ga AND V IN BAUXITE PROFILE

Jagannatha Rao and Krishna Murty (1980), mentioned that due to coherence of Ga with Al, it mostly occurs in kaolinite within the under clay zone and in gibbsite within the bauxite zone.

VI.2.2 : VANADIUM (V) :

Goldschmidt (1929) placed vanadium in the iron family because of its affinity with the later.

Rankama and Sahama (1949) and Goldschmidt (1954) mentioned that V^{3+} (0.65 A^{o}) readily replaces Fe^{3+} (0.67 A^{o}) because of close ionic radii.

Banerjee (1975) and Jagannatha Rao and Krishna Murty (1980) believed that vanadium probably occurs in magnetite, augite and titanium minerals.

It is one of the more abundant trace metal in the study area and its concentration varies from 50 ppm to 700 ppm (Table-X).

Goldschmidt (1954) stated the mechanism involved in the enrichment of vanadium. Vanadate ions removed from augite during weathering process, remain in solution over a wide pH range. It may be locally precipitated in the presence of ferric hydroxide in laterites.

In arid regions, vanadate is released in solution and is concentrated in aluminium hydroxide (Rankama, et al.,

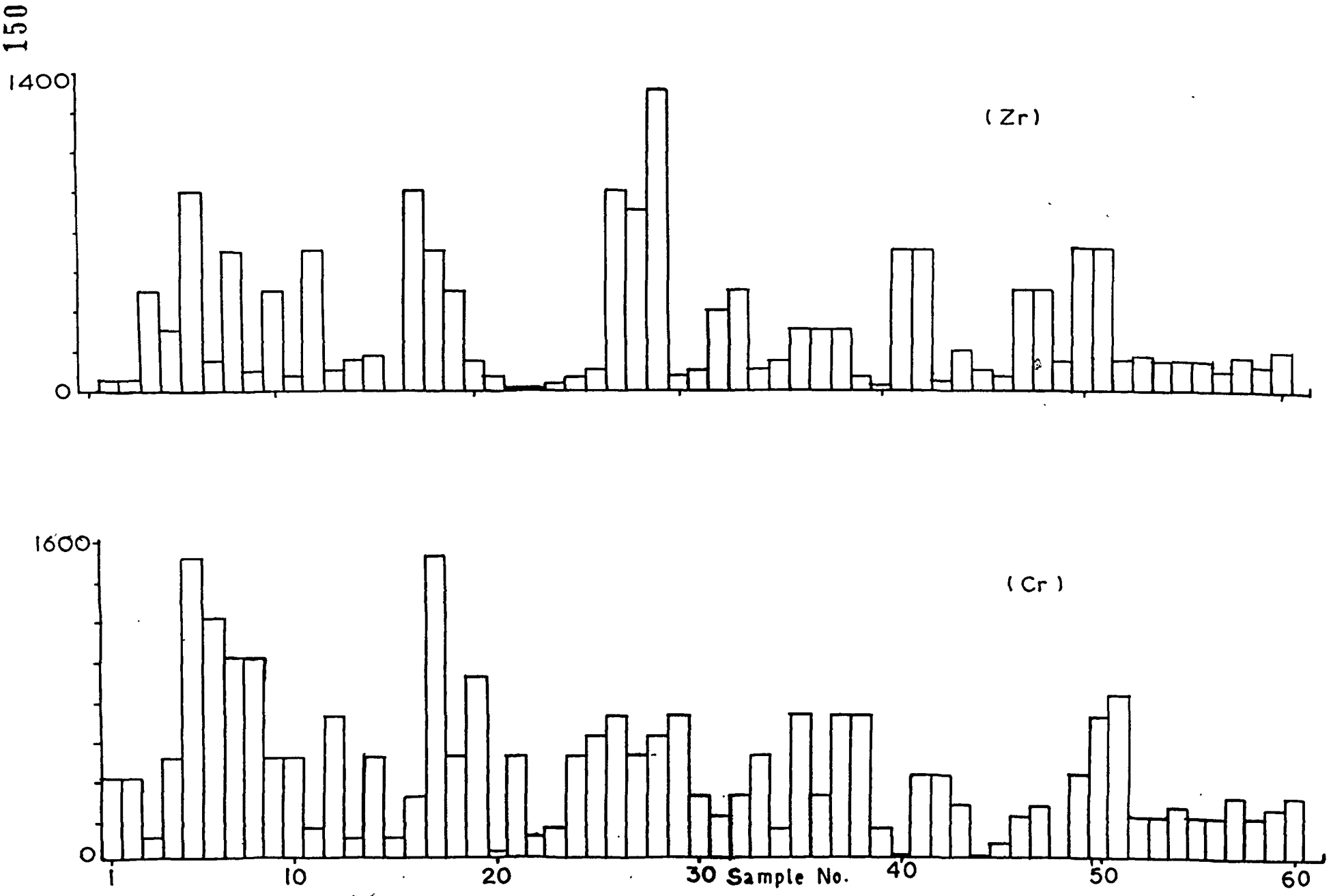


FIG. 33(b) HISTOGRAMS SHOWING DISTRIBUTION OF Zr AND Cr IN BAUXITE PROFILE

1949). Zubovic (1961) stated that vanadium occupies a higher position in organic affinity series.

Since the Shevaroy bauxite is lateritic in nature, higher concentration of vanadium may possibly be due to high ferric hydroxide throughout the bauxite profile.

VI.2.3 : ZIRCONIUM (Zr) :

Geochemically zirconium is lithophile element (Goldschmidt, 1954). Its ionic radius is 0.87 A^{o}.

Mineralogical studies have confirmed the presence of zirconium in the form of very finely divided grains of zircon both in the parent rocks and laterite samples. It is known to be relatively insoluble and hard mineral and its consequent enrichment in the profile in relation to the source rock is obvious.

Banerjee (1975) mentioned zircon as the chief carrier of zirconium in the charnockites.

During weathering zirconium in the form of zircon remains largely in resistates, which contain more of zirconium than hydrolyzates. Some zirconium also goes into solution and is removed by hydrolysis which does not form secondary minerals (Rahman, 1978).

In the study area, its concentration varies from less than 20 ppm to 1500 ppm, as compared to the meagre

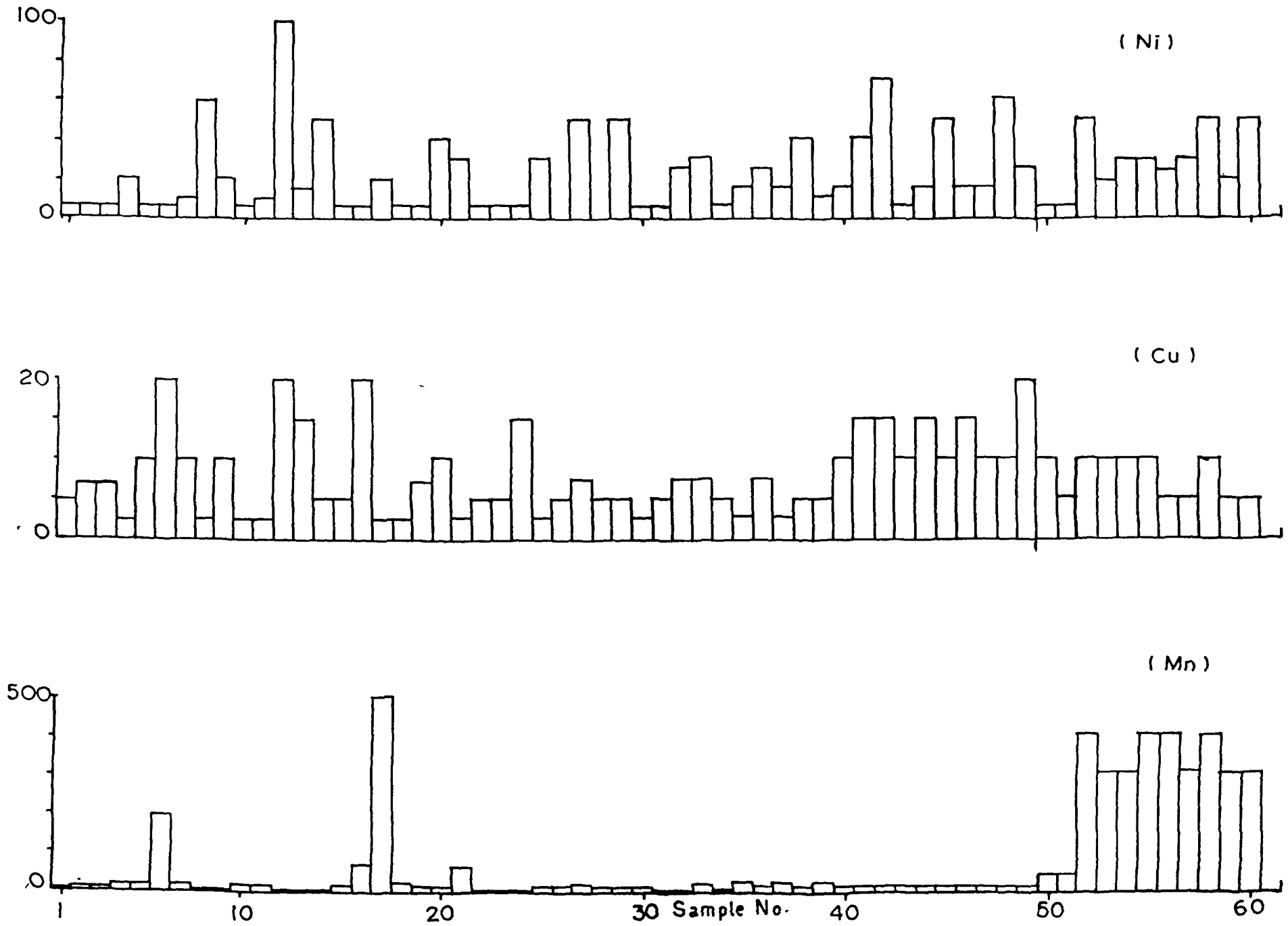


FIG-33 (c) HISTOGRAMS SHOWING DISTRIBUTION OF Ni, Cu AND Mn IN BAUXITE PROFILE

concentration in parent rocks, having an average of 150 ppm of zirconium (Table-X).

Its concentration trend reveals that zirconium is concentrated more than Al throughout the laterite profile regularly (except bauxite zone). This observation is well in conformity with those of Goldschmidt (1937), Gordon and Murata (1952), Wolfenden (1965) and Jagannatha Rao and Krishna Murthy (1980).

The relative variation in the distribution of zirconium within the profile, suggests a similar distribution of zircon in the parent rocks.

VI.2.4 : CHROMIUM (Cr) :

Mason (1966) placed chromium in the group of lithophile elements. It occurs in rocks as Cr^{3+} and is characterized by low mobility. Rankama and Sahama (1949) and Banerjee (1975) stated that in charnockites it occurs in pyroxenes - amphiboles and magnetite.

In the study area, samples of the bauxite profile contain chromium in high concentration (5 to 1500 ppm) which shows an appreciable enrichment as compared to the parent rocks that have an average concentration of 200 to 250 ppm of chromium (Table-X), due to its less mobility and more affinity with Al^{3+} and Fe^{3+}.

Chromium has remained almost uniform in most of the laterite and bauxite samples. Probably most of the chromium in the bauxite profile occurs either in gibbsite or kaolinite.

According to Mc Laughlin (1959) appreciable amount of Cr may occur in kaolinite.

Its higher concentration in bauxite zone could be due to the closeness in the chemical characters and ionic radii of Al^{3+} (0.57 A^{o}) and Cr^{3+} (0.64 A^{o}).

VI.2.5 : MANGANESE (Mn) :

Geochemically, manganese is strongly a lithophile element (Goldschmidt, 1954). However, in the upper lithosphere it is oxyphile. In chemical properties it very much resembles to iron.

In charnockites, manganese probably occurs in garnets; the average concentration of Mn in the parent rocks is 400 ppm. During the chemical weathering its strong depletion and slight enrichment is noticed. Values of Mn content in the samples of bauxite profile varies from less than 10 ppm to 70 ppm. The maximum content of Mn, 200 ppm and 500 ppm is observed in only two bauxitic samples (2/5 and 4/7) (Table-X).

The low ionic potential of Mn^{2+} is susceptible to leaching even in weakly acidic solution, while the higher ionic potential of Mn^{3+} and Mn^{4+} leads to immobilization or precipitation (Goldschmidt, 1958). The strong enrichment of manganese in few samples of lateritic-bauxites in relation to lithomarge in the study area, suggests that Mn is perhaps present in the form of Mn^{4+}, and is associated with Fe^{3+} and Ti^{4+} in the profiles, as divalent Mn never enters in divalent iron. The above postulation is well in conformity with the results obtained as the sample having maximum content of Mn (500 ppm)also contains maximum TiO_2 (4.60%) which is the highest concentration in all the samples of the study area analysed (Table-VI).

VI.2.6 : NICKEL (Ni) :

Nickel belongs to the iron family (Goldschmidt, 1929) or the ferrides (Landgren, 1943). It is very close to iron in the periodic system also. Its ionic radii is (0.69 A^{o}). It is a strong siderophile element and also has an affinity with the chalcophile and lithophile elements as well.

Most of Ni in the parent rock is probably present in ferro-magnesian minerals (Rankama and Sahama, 1949 and Goldschmidt, 1954).

The maximum content of Ni 100 ppm is observed in only one sample while in others it ranges from less than 10 ppm to 70 ppm as compared to the parent rock concentration which ranges in between 20 ppm and 50 ppm (Table-X). Rahman (1978) also noticed Ni concentration in the bauxites and laterites of Lohardaga varying in between 12 ppm to 50 ppm.

During the weathering of ferro-magnesian minerals nickel will remain in solution with ferric ions and Mg will be removed. The presence of Ni in the ferric hydroxide minerals in the bauxite zone is therefore well expected. But out of expectations, its less concentration could be explained due to its moderately soluble nature and ionic potential less than 3, results it to readily pass into ionic solution resulting its depletion, which is well observed in the Shevaroy bauxite samples (Table-XII). Seeliger (1962), based his studies on the 'soft iron ore' of Conakry, Guinea, also postulated that nickel is adsorbed on the surface of goethite crystals.

Zeissink (1969) stated that enrichment of nickel in the ferruginous zone of Greenvale laterite is due to its probable entry in the lattice of goethite and hence its hindered downward migration. In 1971, for the same

profile, he postulated that 'as weathering proceeds, Ni together with Zn, Mn and Co eventually migrate from the zone of ferruginous horizon into lower clay zone.

VI.2.7 : COBALT (Co) :

Cobalt belongs to the iron family (Goldschmidt, 1929 and Landgren, 1943). It is considered as an element of ferro-magnesian minerals in the parent rocks which upon chemical weathering is converted to goethite or limonite. These minerals are considered likely to contain Co in the lateritic zone, though coherence between cobalt and iron is poor (Jagannatha Rao and Krishna Murthy, 1980).

The content of coblat in the samples of bauxite profile is almost uniform throughout the profile which is less than 10 ppm (except only one lateritic sample which contains 15 ppm), shows a marked depletion as compared to the parent rocks having an average of 15 ppm to 30 ppm cobalt. (Table-X). The low content of cobalt in these bauxites is probably due to high content of iron in them which has no marked coherence with it.

VI.2.8 : LEAD (Pb) :

Goldschmidt (1937) placed lead in the group of

both siderophile and chalcophile elements. It is a divalent cation and its ionic radii is (1.32 A^{O}). In the lithosphere, it shows a marked affinity with sulphur and oxygen.

According to Banerjee (1975), in charnockites, Pb is associated with the potassic-feldspars.

The maximum content of Pb (200 ppm) is observed in only one sample (4/7) in which titanium and iron concentration is also high. On the contrary, in the remaining samples, the lead content is almost uniform throughout the bauxite profile.

VI.2.9 : ZINC (Zn) :

Goldschmidt (1937) included zinc in the chalcophile group, probably due to its affinity with sulphides. Jagannatha Rao and Krishna Murthy (1980) mentioned that Zn^{2+} closely resembles to Cu^{2+} as both have similar ionic radii (Zn^{2+}, 0.74 A^{O}; Cu^{2+}, 0.72 A^{O}). It therefore shows a strong coherence to Cu.

Concentration of zinc in the study area varies from less than 20 ppm to 50 ppm as compared to the parent rock having an average concentration of 20 ppm to 50 ppm (Tables-X & XII).

The mobility of zinc is moderately high and is limited by organic activity and is expressed to show co-precipitation with limonite (Hawkes and Webb, 1965). This observation is well in agreement in the study area also, where the bauxitic samples are poor in zinc concentration as compared to the lateritic samples. High content of zinc in sample nos. 1/3, 2/2 and 6/2 could be correlated to the high content of ferric-hydroxide minerals present. On the other hand its concentration in the clay zone could be due to its adsorption property. In the study area, zinc exhibits almost steady increase from charnockite to their laterite products.

VI.2.10 : COPPER (Cu) :

Goldschmidt (1937) included copper in the group of chalcophile elements as it shows high affinity for sulphur.

The maximum content of Cu in the bauxites of the study area is 20 ppm, which reveal slight enrichment as compared to the parent rocks having Cu content in between 5 and 10 ppm (Table-X).

Jagannatha Rao and Krishna Murthy (1980) stated that the ionic potential of Cu^{2+} is less than 3, hence it is expected to pass into ionic solution and therefore

it should be depleted. In the study area, it is observed that copper is enriched slightly in many of the samples. The relative concentration could have been brought about by events subsequent to bauxitization as explained by Gordon and Murata (1952) for Arkansas bauxites, or due to the other factors such as selective adsorption,pH, oxidation and role of organic matter (Zeissink, 1969).

Since this element is known to be a good adsorbent and its activity increases with free surface, the view corroborates well with the view expressed by Banerjee (1975) and Balasubramaniam (1978).

According to Krauskopf (1956) and Wagner, et al. (1980), copper is mainly associated with clays. In the study area too there is an enrichment of copper in the clay samples because of its high adsorption property (Table-XII).

VI.2.11 : BARIUM & STRONTIUM (Ba & Sr) :

Both barium and strontium are the elements of alkaline earth metals. Rankama and Sahama (1949) and Jagannatha Rao and Krishna Murthy (1980) mentioned that mainly feldspar, and rarely augite are the chief carrier of Ba and Sr in the parent rocks. Rankama and Sahama further mentioned that Ba^{2+} accompanies K^{+} by virtue of

their similar ionic radii (Ba^{2+} 1.34 A^{o}; K^{+} 1.33 A^{o}), while Sr^{2+} accompanies Ca^{2+} (Sr^{2+} 1.12 A^{o}; Ca^{2+} 0.99 A^{o}), hence Ba and Sr are present in the K-feldspar and plagioclase-feldspars respectively.

In the present study, the content of Ba and Sr is almost uniform throughout the profile, which is less than 50 ppm and less than 100 ppm respectively (Table-X), showing marked depletion as compared to the parent rocks, having an average of 800 ppm of Ba and Sr. But in the zone of lithomorphic clay their concentration is slightly higher and reaches up to 400 ppm (Ba) and 100 ppm (Sr), which suggests that they are possibly held up by adsorption in clay minerals (Table-XII).

Goldschmidt (1954) mentioned that during process of chemical weathering which leads to bauxitization, these alkaline earths (Ba & Sr) together with alkalies are removed in solution and thus their depletion takes place. A similar trend of depletion is also observed by a number of workers (Gordon and Murata, 1952 and Wolfenden, 1965) for Arkansas and Sarawak bauxites respectively.

Trace elements viz., Li, Sr, Mo, Zn, Ge, Ba, and Y show almost uniform trend of distribution throughout the profile.

VI.3 : ROLE OF pH IN THE SYNTHESIS OF TRACE METALS :

Goldschmidt (1958) considered pH a major chemical factor to understand the geochemical behaviour of elements and mentioned that the migration of elements in the landscape is related to the pH of the environment.

It is now well established and well known fact that the physico-chemical environment or pH of the circulatory water controls the migration, precipitation and fixation of trace elements in the various zones of the bauxite profile.

Generally, it is observed that there are only a few elements which do not leach out over a wide range of pH; otherwise most of the trace elements go into solution at low pH and precipitate at higher pH (Hawkes and Webb, 1974).

The inter-relative study between trace elements and pH, has been taken in order to understand the geochemical behaviour of trace elements during the process of chemical weathering in the bauxite profile.

As mentioned earlier, there are certain trace elements which have close affinity with the major elements and hence their distribution or dispersion in the profile is governed by the same physico-chemical environment - for example, Ga follows the trend of alluminium and V

follows the trend of iron during the weathering cycle. Dispersion of even the same element varies in the different zones of the profile, because the pH of various zones depend upon the nature of ground water percolating water which acts as a universal solvent. During chemical weathering the water leaches out the most soluble contents (alkalies and alkaline earths) of the parent rock and its neutral behaviour changes into alkaline nature. It acquires certain distinctive properties as compared to water which were not in contact with the rocks encountered in its circulatory path.

The nature or quality of water varies according to the contact of the rocks and this reflects in the concentration of various elements in the different zones from the same parent material.

Britton (1955) determined the pH of hydrolysis of certain elements. The pH at which elements precipitate as hydroxides is known as pH of hydrolysis which for various elements is given in Table-XIII.

TABLE - XIII : pH of hydrolysis (hydroxide precipitation) of some elements from dilute solution (from Britton, 1955).

Elements	pH
Cu^{2+}	5.3
Cr^{3+}	5.3
Pb^{2+}	6.6
Ni^{2+}	6.7
Co^{2+}	6.8
Zn^{2+}	7.0
Mn^{2+}	8.5-8.8

For instance, at low pH some elements are likely to be precipitated, other elements do not precipitate until much higher pH values are reached, such as copper at a pH of 5.3 and zinc at pH of 7.

Hence, it is clear from the above discussion that pH is a major factor in the migration or precipitation of these elements. On the other, it has also been observed that the elements of different pH on hydrolysis even may be precipitated together, reflects that not only pH, that controls the trace element migration and fixation or

redeposition, but vegetation, nature of rock types in contact, nature of the impurities present in water and the differences or closeness in water and the differences or closeness in the values of ionic potential are the other factors which control migration, sorption and enrichment of various metals in a particular medium.

Valance states of the elements have also a major relation with pH, for instance, the low ionic potential of Mn^{2+} is susceptible to leaching even in weakly acidic solution (low pH), while the higher ionic potential of Mn^{3+} and Mn^{4+} leads to immobilization or precipitation. The pH of hydrolysis of Zn^{4+} is 2 and Zn^{2+} is 7 (Britton, 1955).

Goldschmidts (1954) noted that vanadate (V^{3+}) ions during weathering remain soluble over a wide range of pH and they may locally precipitate in the presence of hydroxides of ferric ions. The enrichment of vanadium with Fe_2O_3 in the weathering profile suggests that high ferric hydroxide content in the laterite may be responsible for fixation of high vanadium concentration because of closeness in ionic potential V^{3+} (4.65) and Fe^{3+} (4.48).

Fortescue (1979) stated that the pH of hydrolysis of (Mn^{2+}) is in between 8.5 to 8.8 and its concentration is a function of pH; hence at higher pH range the concentration of Mn is high and at lower pH range the concentration of Mn is low.

In the present investigation, the parent rock composition influenced the pH of the solution and makes it acidic, which generally favoured the migration of most of the trace elements instead of their fixation in the profile.

VI.4 : INTER-RELATIONSHIP BETWEEN MAJOR & TRACE METALS :

In order to study the inter-relationship between the major and trace elements, and between the trace elements themselves, analytical values were plotted against each other and noted the various type of relationships between them. It has been observed that many of the trace elements show or maintain a sympathetic relationship with Al and some of them also exist in more than one association. The behaviour or relationship trend of the different elements in the different zones of the profile have been shown separately. Association of the different elements in the bauxite profile proved helpful in understanding the genesis of the deposit and similarity in chemical characters of the host rock and its derivatives. The concentration of various trace and major elements in various units of the bauxite profile is given in Tables-IX & X.

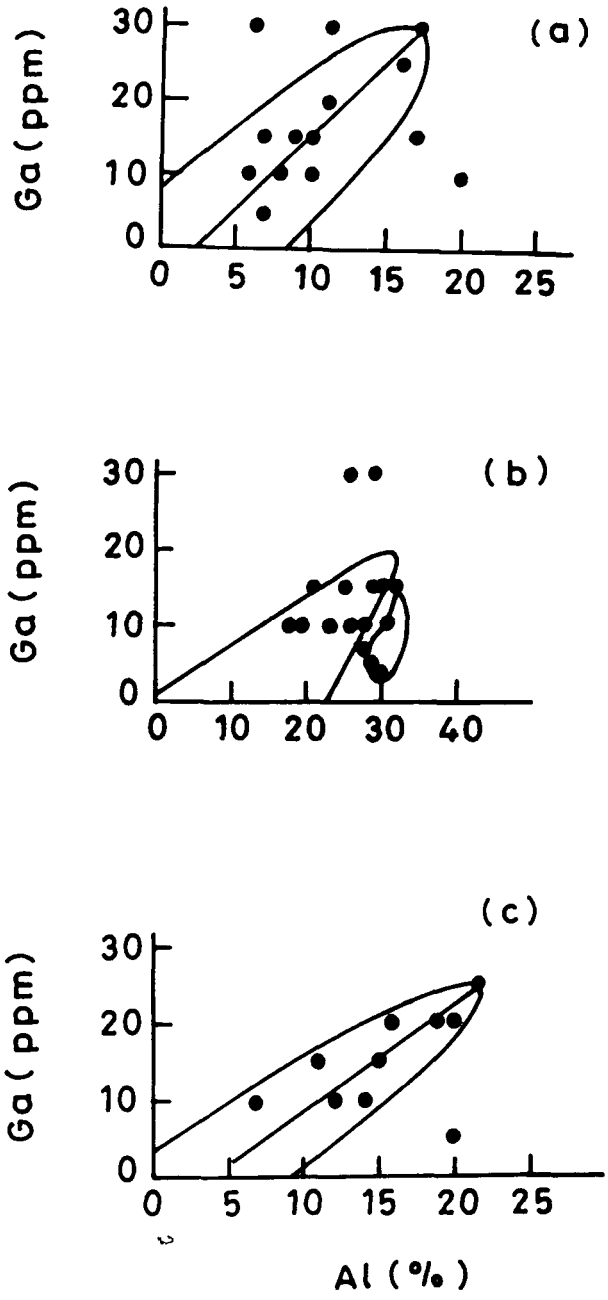


FIG. 34 CORRELATION DIAGRAM OF Ga Vs. Al IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

VI.4.1 : GALLIUM VS. ALUMINIUM :

Gallium shows positive relation with aluminium (Figs. 34 a, b & c). It reveals a gradual enrichment from bed rock upwards to the bauxite zone with the enrichment of aluminium. A similar enrichment of gallium with aluminium has been indicated for bauxite deposits found associated with basaltic rocks in Bihar and Gujarat (Chowdhary, et al., 1965). Gallium behaves similar to aluminium because of similarity in their ionic radii (Shaw, 1957). This coherence is reflected in the increase of gallium with the increase of aluminium (Jagannatha Rao and Krishna Murthy, 1980), in the bauxite profile of the study area too.

VI.4.2 : CHROMIUM VS. ALUMINIUM :

The relationship between chromium and aluminium is found to be positive throughout the bauxite profile (Figs. 35 a, b & c), Mc Laughlin (1959), mentioned that appreciable amount of chromium may occur either in kaolinite or gibbsite (aluminous minerals). Other possible reasons for its concentration in the bauxite are the similar chemical characters and ionic radii of Al^{3+}(0.57 A^{o}) and Cr^{3+} (0.63 A^{o}). The coherence of chromium with aluminium

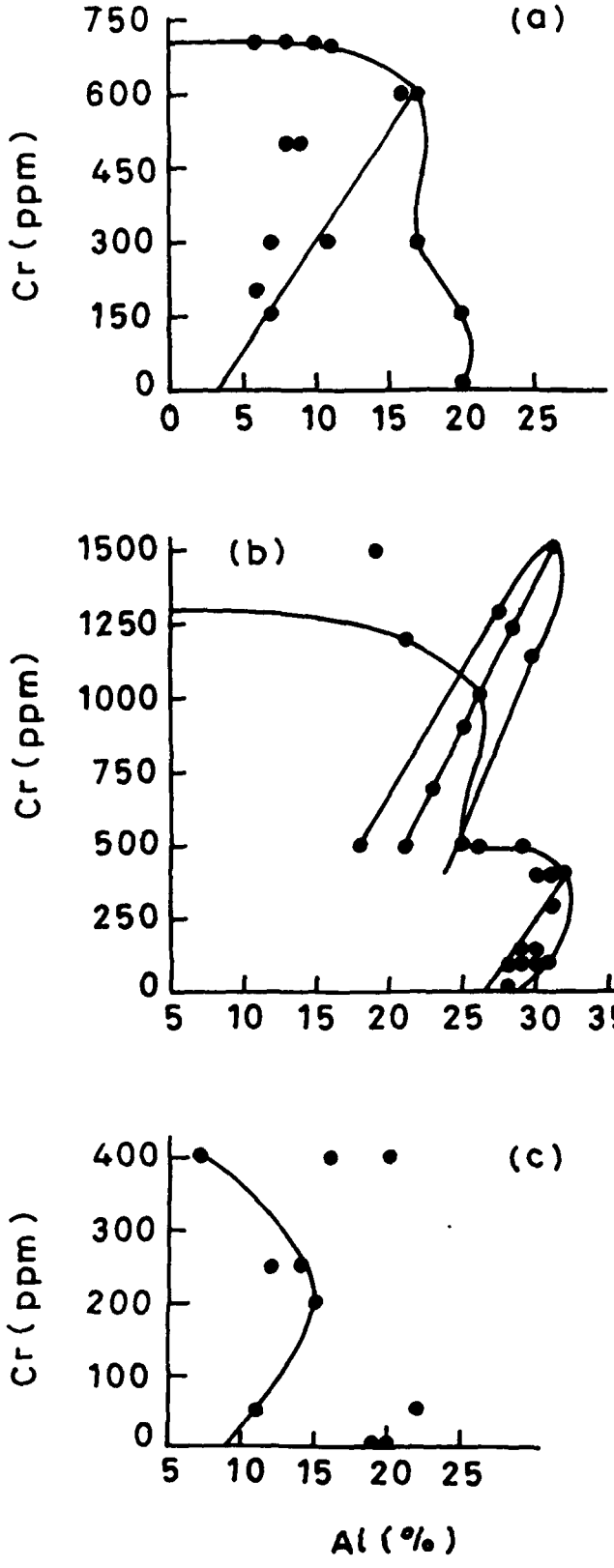


FIG. 35 CORRELATION DIAGRAM OF Cr Vs. Al IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

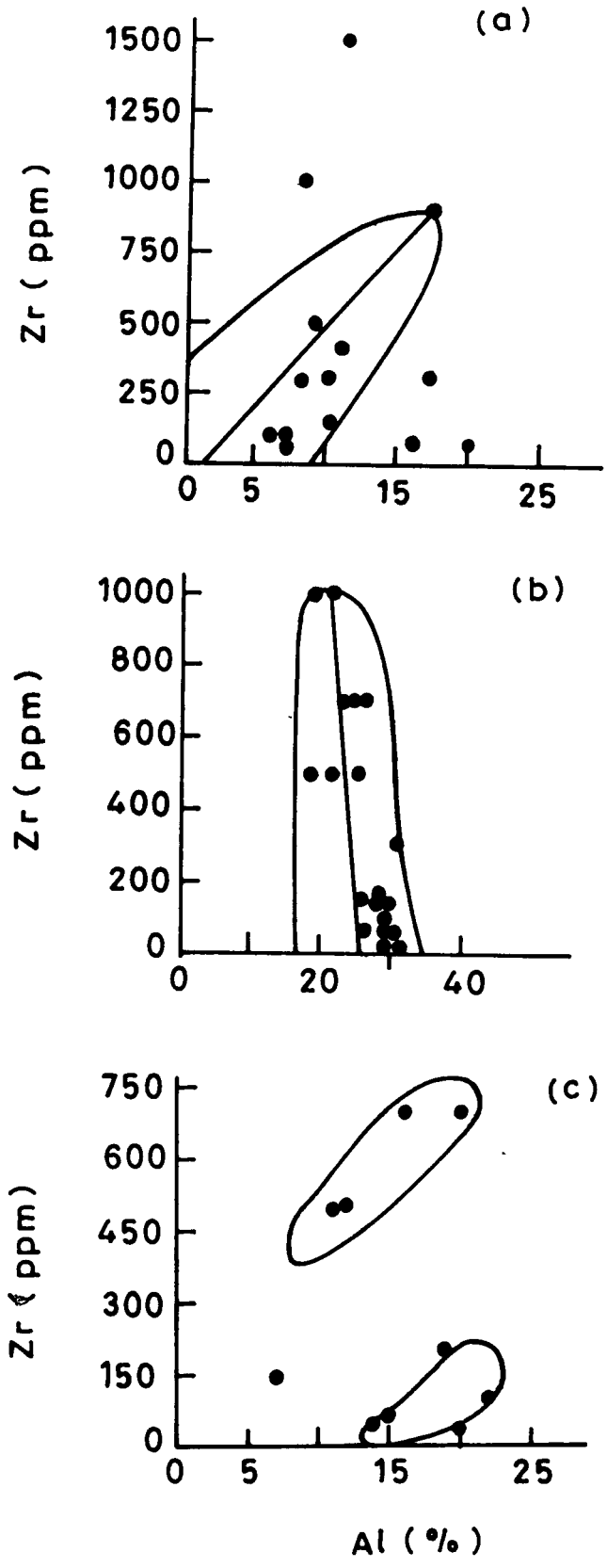


FIG.36 CORRELATION DIAGRAM OF Zr Vs. Al IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

in the bauxite profile is also reflected by the presence of chromium in aluminous minerals and enriches in them with the increasing degree of weathering.

VI.4.3 : ZIRCONIUM VS. ALUMINIUM :

They show a sympathetic relationship over most part of the bauxite profile (Figs. 36 a, b & c).

Vertical relationship trend reveals that zirconium is concentrated more than aluminium throughout the bauxite zone. Same observations are also reported by Goldschmidt (1937) and Gordon and Murata (1952). Its positive trend of relationship with aluminium may also be possible due to its resistant nature. Rahman,(1978) believed that accommodation of zirconium in aluminium hydroxide minerals, causes sympathetic relationship between each other.

VI.4.4 : MANGANESE VS. ALUMINIUM :

The relationship between manganese and aluminium is not definite throughout the bauxite profile (Figs. 37 a, b & c). In the zone of lithomargic clay, the concentration of manganese remains quite uniform with respect to iron concentration, suggests the immobilization or precipitation

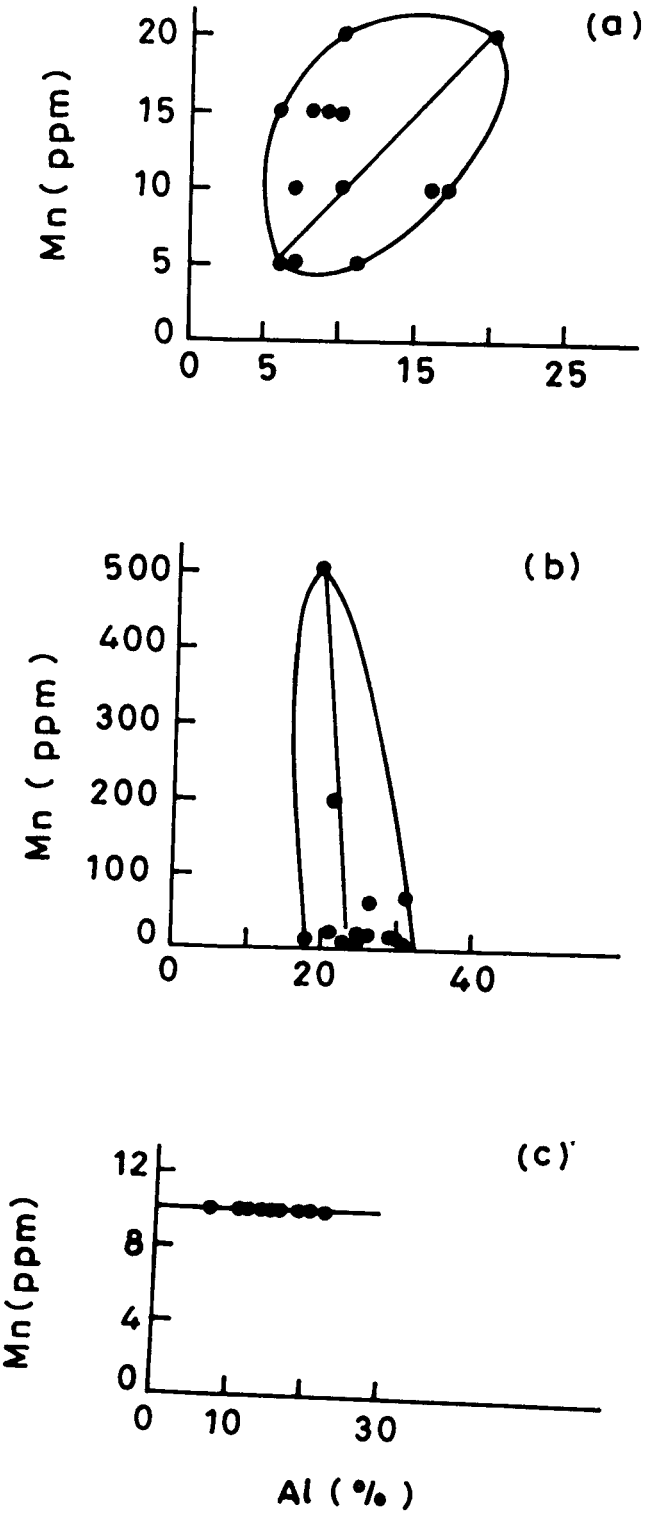


FIG. 37 CORRELATION DIAGRAM OF Mn Vs. Al IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

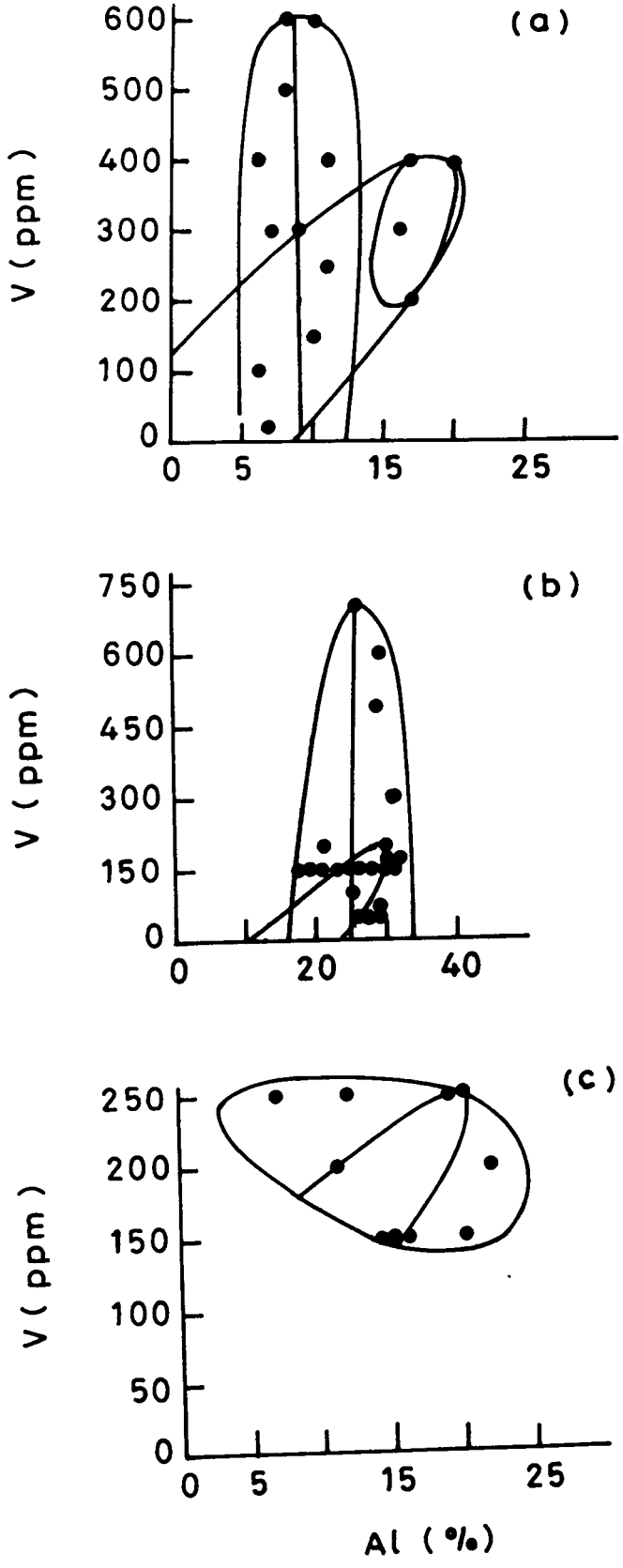


FIG.38 CORRELATION DIAGRAM OF V Vs. Al IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

of Mn^{4+}, because of higher ionic potential. In the lateritic zone manganese shows a weak positive relation with aluminium due to its association with iron and titanium in this zone, and closeness in ionic radii Mn^{4+} (0.60 A^{o}) and Al^{3+} (0.57 A^{o}).

VI.4.5 : VANADIUM VS. ALUMINIUM :

There exists a weak sympathetic rather vertical relationship between vanadium and aluminium (Figs. 38 a, b & c). This trend of relationship reveals that vanadium is concentrated more than aluminium throughout the bauxite profile. Vanadium follows the enrichment trend of ferric hydroxides instead of aluminium hydroxides, but presence of ferric and aluminium hydroxides together, explains its high concentration even in the bauxite zone.

VI.4.6 : CHROMIUM VS. IRON :

Sympathetic behaviour in between chromium and iron occurs in the various zones of bauxite profile (Figs. 39 a, b & c).

In charnockites, chromium occurs together with iron in the ferro-mangnesians. During chemical weathering, it more or less follows the trend of iron because of the

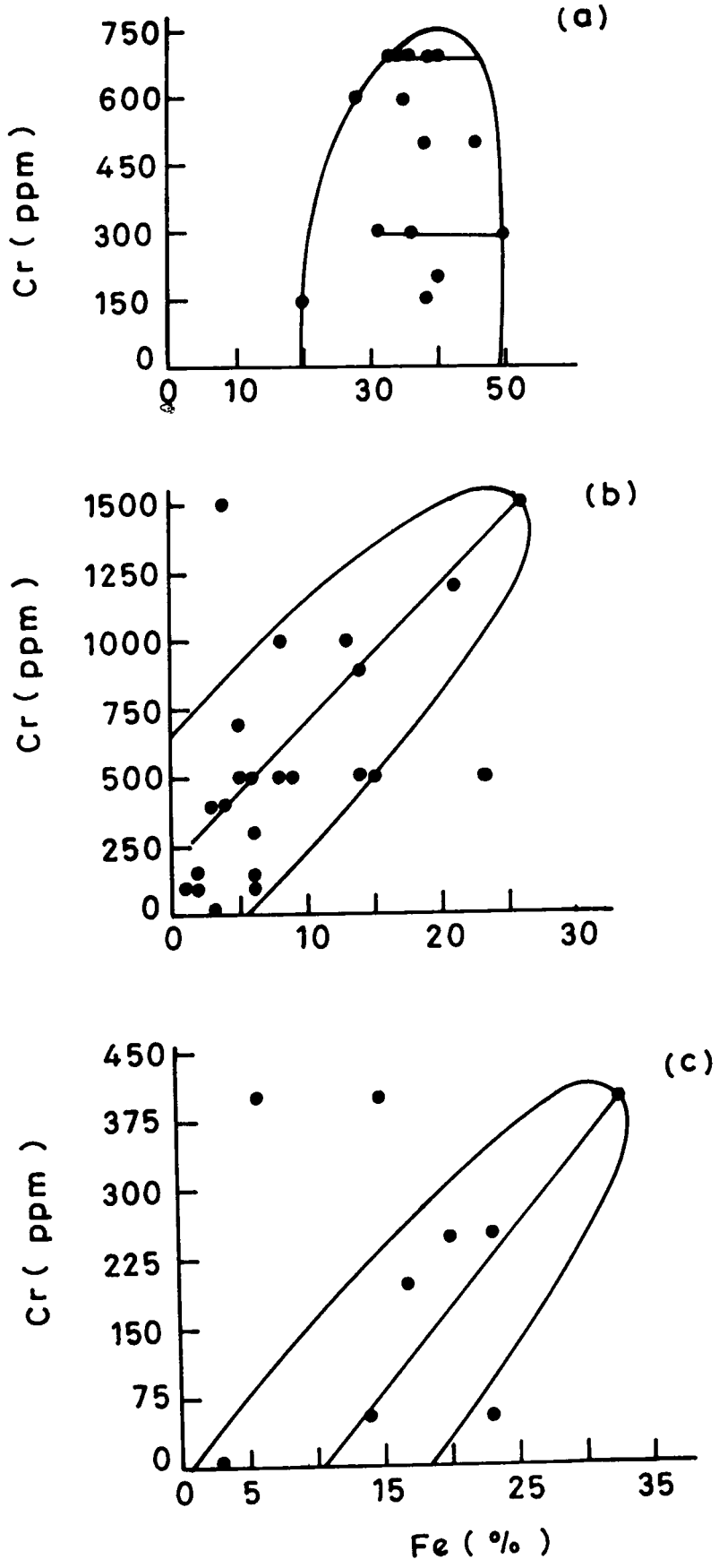


FIG. 39 CORRELATION DIAGRAM OF Cr Vs. Fe IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

similar ionic radii (Goldschmidt, 1954) of Cr^{3+} (0.63 A^{o}) with Fe^{3+} (0.64 A^{o}).

In bauxites, no chromium mineral is observed, and most of the chromium probably occurs either in gibbsite or kaolinite (Mc Laughlin, 1959). These minerals are probably distributed throughout the bauxite profile together with goethite and hematite and therefore explains the reasons of the sympathetic behaviour between the two.

VI.4.7 : VANADIUM VS. IRON :

There exists a positive relationship between vanadium and iron in the different zones of the bauxite profile (Figs. 40 a, b & c). V^{3+} is more closely related to Fe^{3+} than Al^{3+} (Kalsotra and Prasad, 1980). In the bauxite profile of the study area, vanadium increases upwards and towards the lateritic zone, indicating thereby that it follows the pattern of Fe_2O_3 enrichment in the *prorile*.

According to Goldschmidt (1958) vanadate ions on weathering remain soluble over a wide range of Eh and pH and they may locally be precipitated in the presence of the hydroxides of ferric iron. The enrichment of vanadium with Fe_2O_3 in the weathering profile, suggests

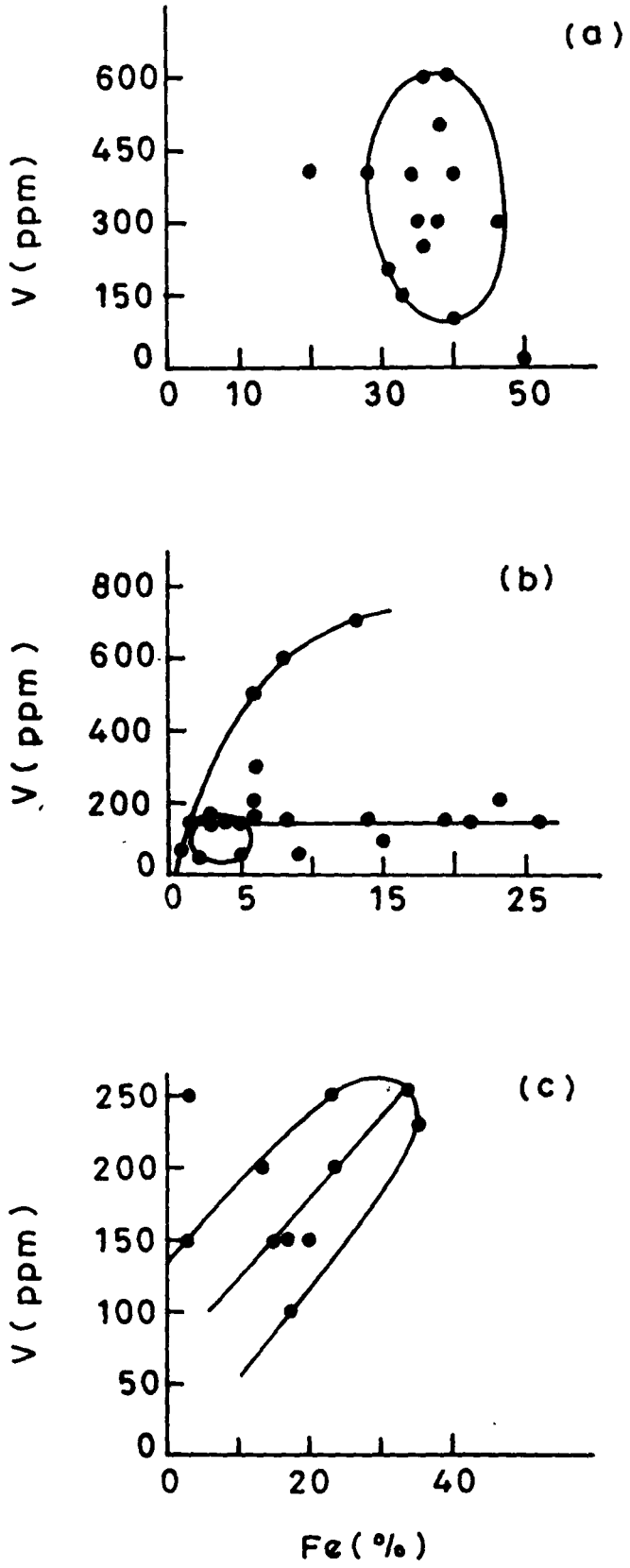


FIG. 40 CORRELATION DIAGRAM OF V Vs. Fe IN
(a) LATERITE
(b) BAUXITE

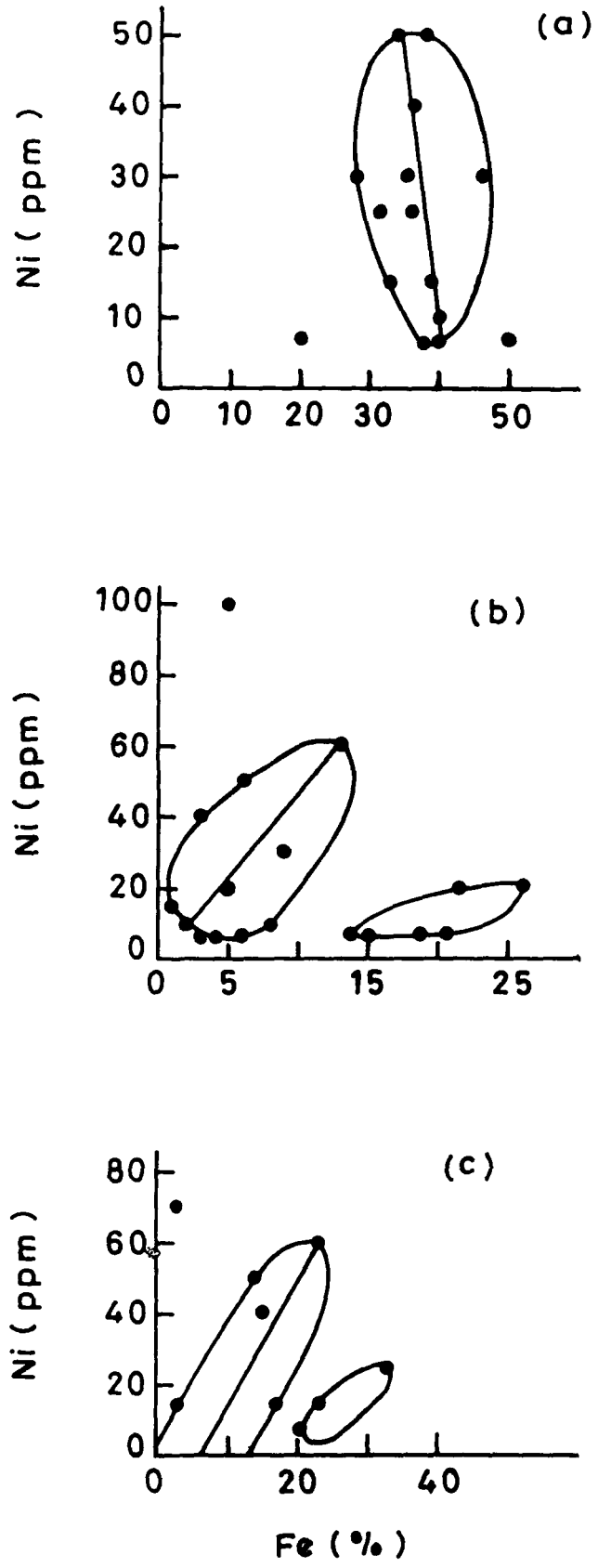


FIG. 41 CORRELATION DIAGRAM OF Ni Vs. Fe IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

that high ferric hydroxide content in the laterite may be responsible for the fixation of vanadium in that zone. Jagannatha Rao and Krishna Murthy (1980) also explained the same reason for vanadium concentration in the bauxite profile of Hazaridadar and Raktidadar areas in Madhya Pradesh.

VI.4.8 : NICKEL VS. IRON :

A positive relationship has been found in between Ni and Fe (Figs. 41 a, b & c) possibly due to the fact that both these constituents belong to the same family (Goldschmidt, 1929). In the periodic system also nickel is the neighbour of iron.

Together with iron, nickel also occurs in the ferro-magnesians of charnockites. During chemical weathering nickel is adsorbed on the surface of goethite crystals (Seeliger, 1962 and Zeissink, 1969). Similar trends in the nature of their enrichment may also be due to the closeness in their ionic radii (Ni^{2+} 0.69 A^{o} and Fe^{3+} 0.64 A^{o}).

VI.4.9 : MANGANESE VS. IRON :

There exists a random relationship between manganese and iron (Figs. 42 a, b & c). In the zone of

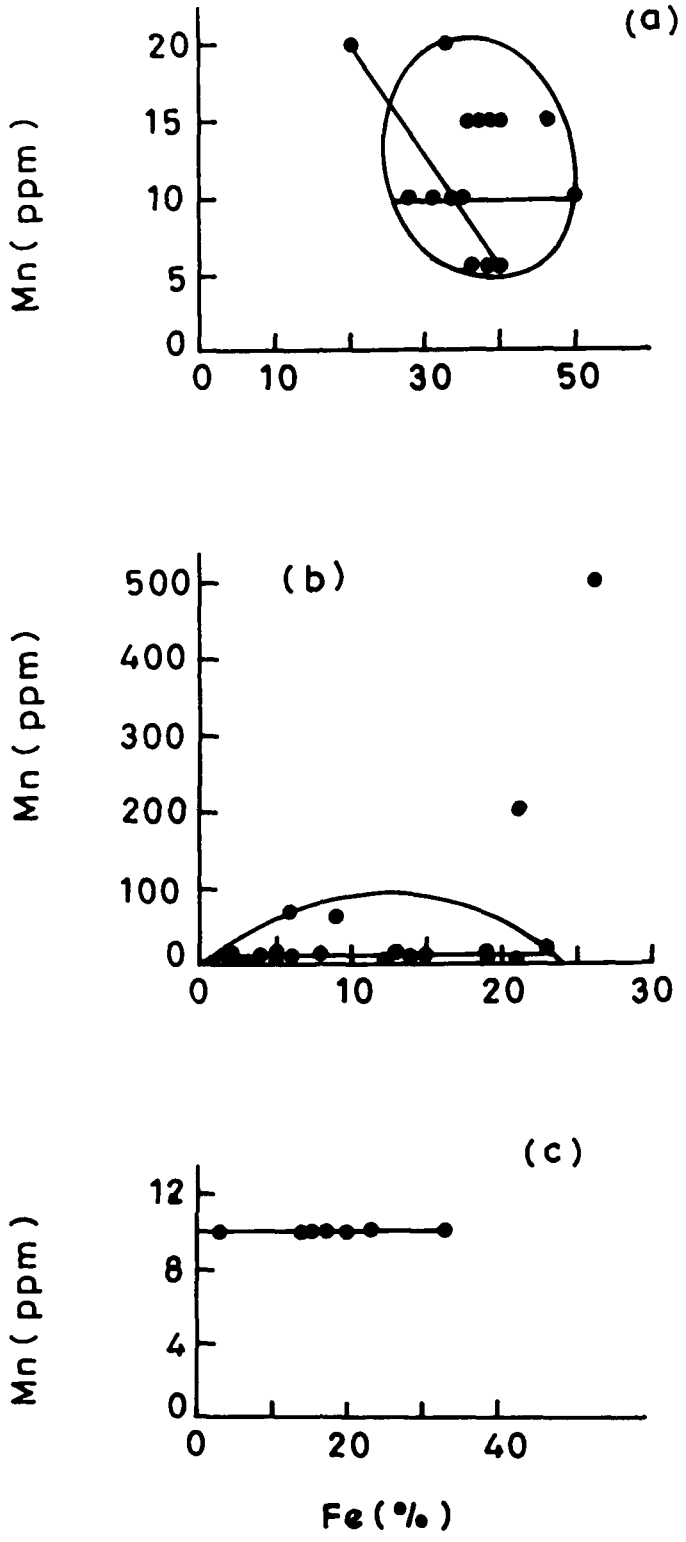


FIG. 42 CORRELATION DIAGRAM OF Mn Vs. Fe IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

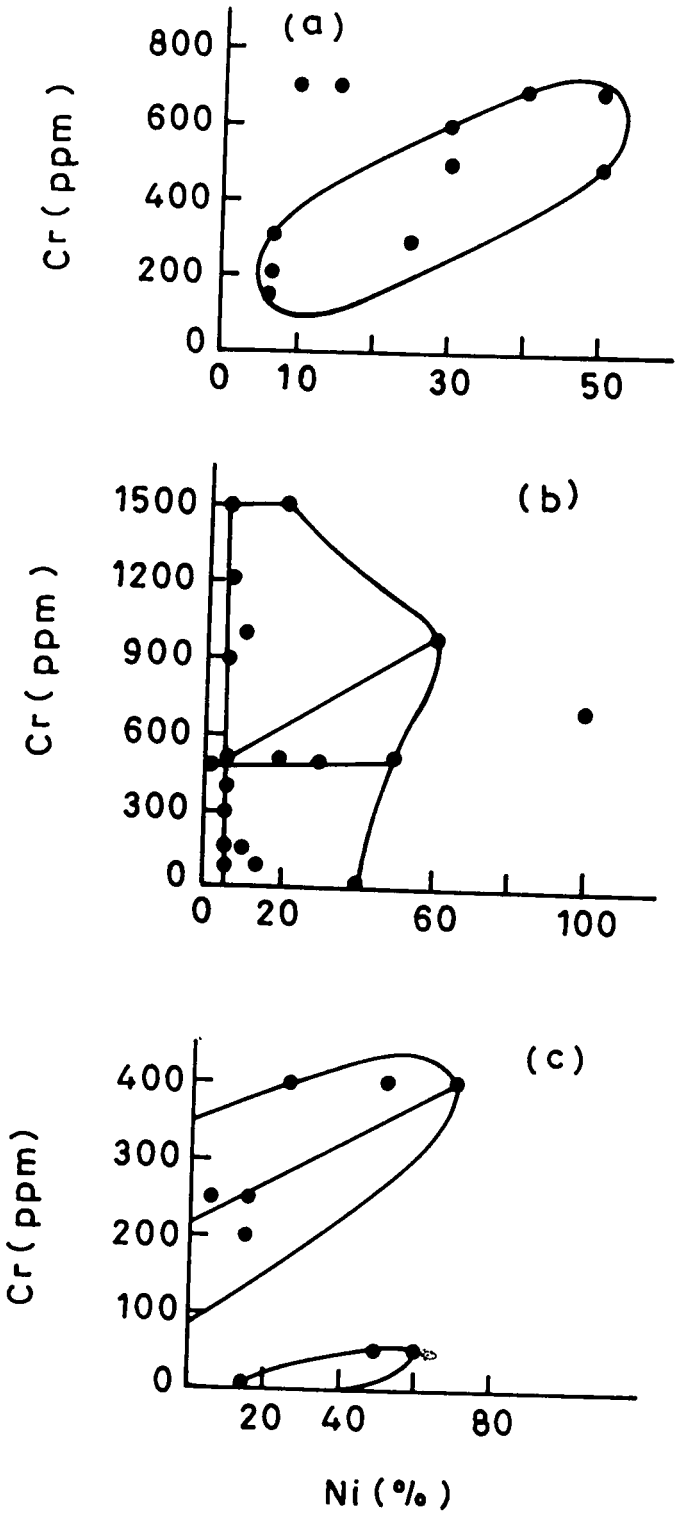


FIG 43. CORRELATION DIAGRAM OF Cr Vs. Ni IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

lithomargic clay, manganese concentration is quite uniform with respect to iron concentration and hence a horizontal relationship exists between them. In the bauxite and laterite zones, its concentration increases slightly with the enrichment of iron, because of its resemblance to iron in chemical characters and ionic radii (Mn^{4+} 0.60 A^{o} and Fe^{3+} 0.64 A^{o}).

VI.4.10 : NICKEL VS. CHROMIUM :

Positive relationship between nickel and chromium has been observed throughout the bauxite profile (Figs. 43 a, b & c).

In the charnockites both nickel and chromium are the constituents of ferro-magnesian minerals, which during weathering follows the same trend of enrichment, possibly due to the similarity in chemical characters and their ionic radii (Ni^{2+} 0.69 A^{o} and Cr^{3+} 0.63 A^{o}), which may cause isomorphic substitution between each other.

VI.4.11 : VANADIUM VS. GALLIUM :

They maintain sympathetic relationship throughout the bauxite profile (Figs. 44 a, b & c). In the bauxite

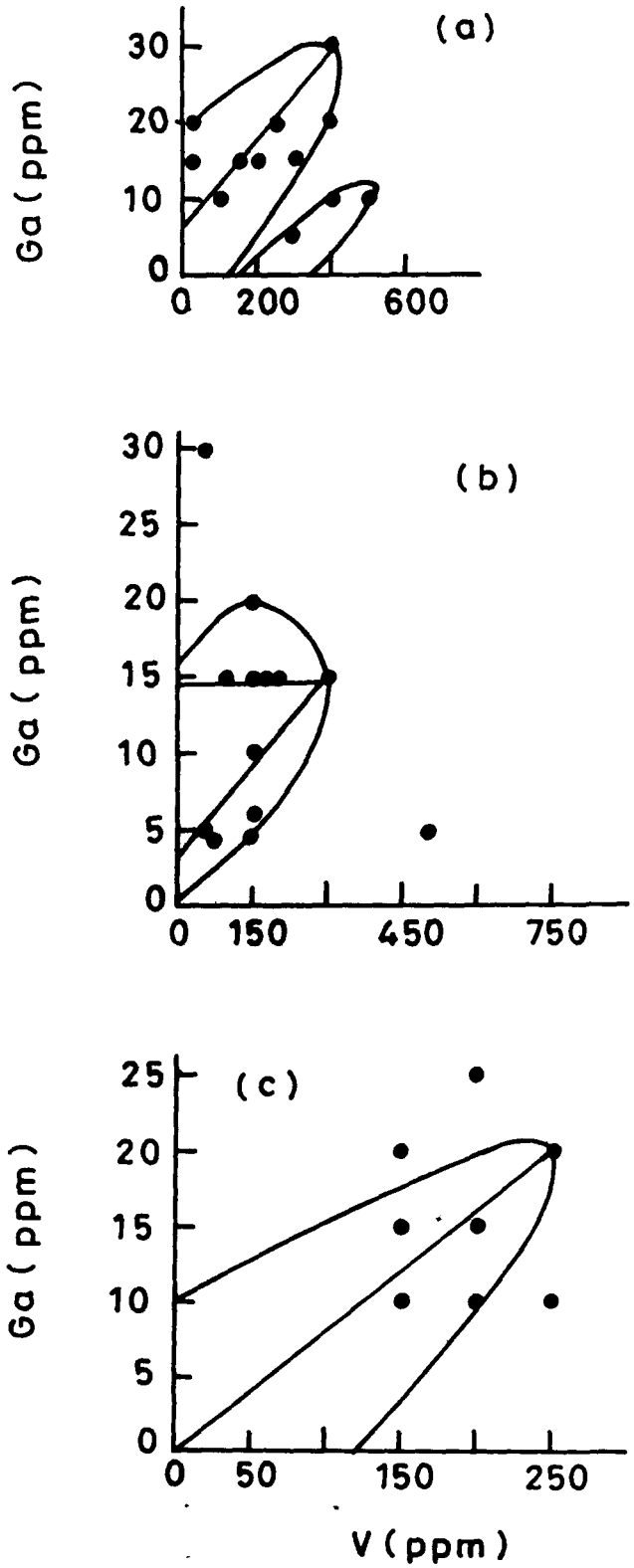


FIG. 44 CORRELATION DIAGRAM OF Ga Vs. V IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

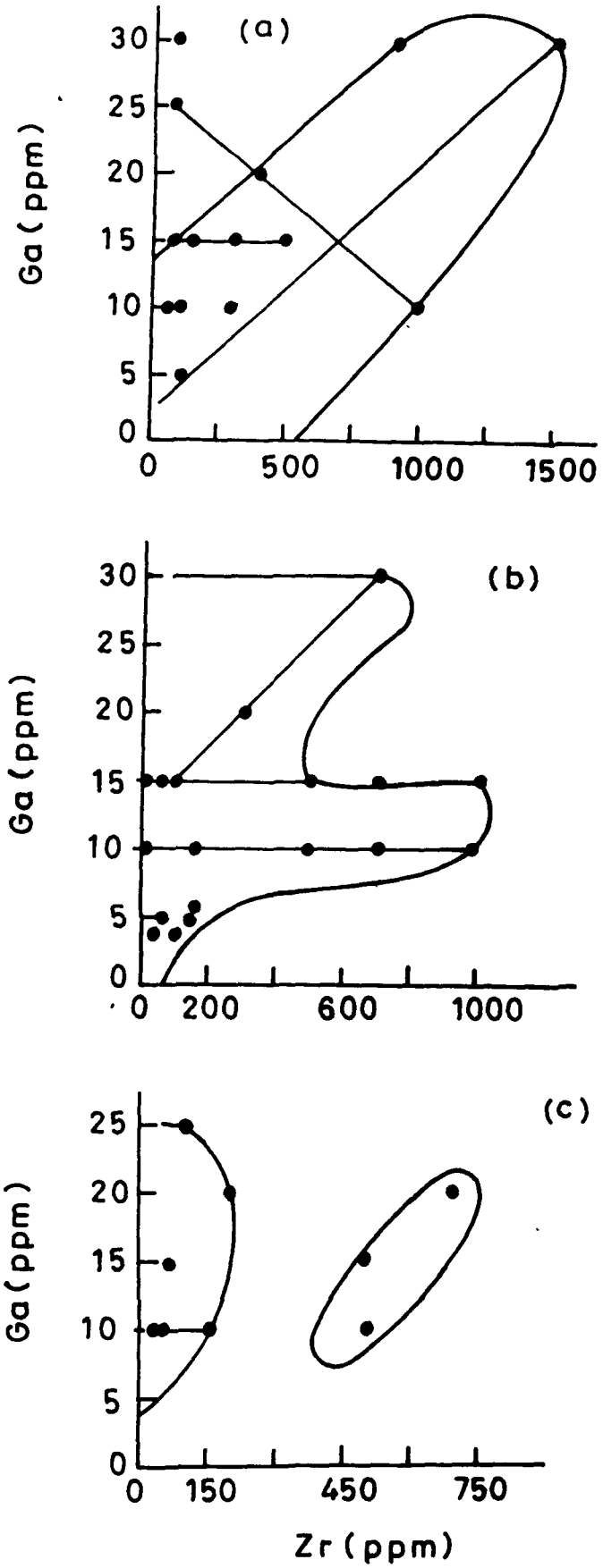


FIG. 45 CORRELATION DIAGRAM OF Ga Vs. Zr IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

zone vanadium does not show strong sympathy with gallium, because in this zone concentration of aluminium hydroxide increases which might have accommodated more gallium than vanadium. Goldschmidt (1954) stated that high vanadium in the laterite zone is due to the high ferric hydroxide content.

VI.4.12 : ZIRCONIUM VS. GALLIUM :

Positive but insignificant relationship between zirconium and gallium has been noticed in the bauxite profile samples of the study area (Figs. 45 a, b & c).

The trend exhibits that zirconium is concentrated more than gallium throughout the bauxite profile. As stated earlier, gallium is generally camouflaged by aluminium mineral due to similar ionic radii, while the ionic radii of Zr is 0.79 A^{o}, having much difference and therefore show weak sympathy with gallium. Positive relationship between zirconium and gallium may possibly be due to the fact that both these elements are mostly incorporated into gibbsite and anatase during neo-mineralization.

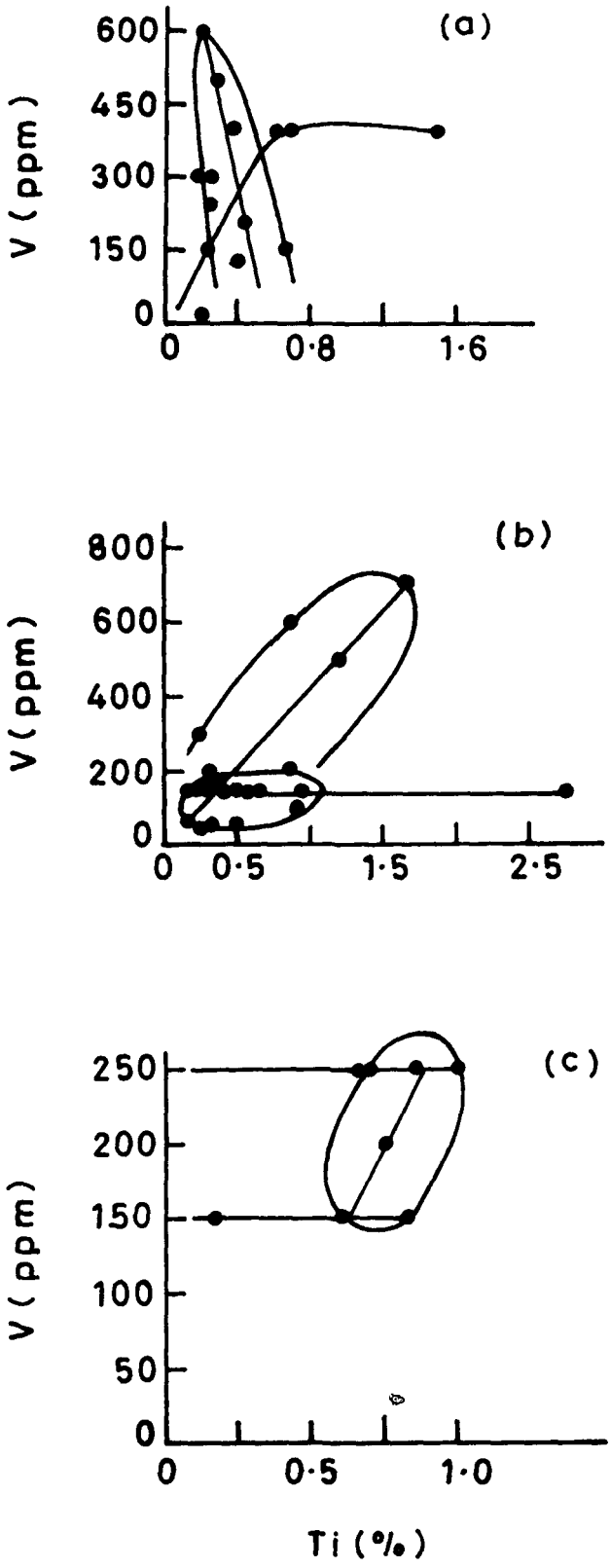


FIG. 46. CORRELATION DIAGRAM OF V Vs. Ti IN
(a) LATERITE
(b) BAUXITE
(c) CLAY

VI.4.13 : VANADIUM VS. TITANIUM :

Sympathetic relationship between vanadium and titanium in the Shevaroy bauxite profile has been found (Figs. 46 a, b & c).

Rankama and Sahama (1949) mentioned that V^{4+} (0.61 A^{o}) can replace Ti^{4+} (0.64 A^{o}). High content of vanadium in the bauxite profile in the study area could possibly be due to the high TiO_2 content, especially in gibbsite and other aluminium bearing minerals (Jagannatha Rao and Krsihna Murthy, 1980).

VI.4.14 : GALLIUM VS. TITANIUM :

A positive relationship exists between these two elements throughout the bauxite profile (Figs. 47 a, b & c).

Rankama and Sahama (1949) pointed out that due to similarity in ionic radii Ga^{3+} (0.62 A^{o}) and Ti^{4+} (0.64 A^{o}), they behave alike, during chemical weathering. Chowdhary et al. (1965) stated that association between gallium and titanium on the basis of ionic radii is difficult to explain and he emphasized various factors such as complex formation, sorption, colloidal phenomena, etc. for their association in the bauxite profile.

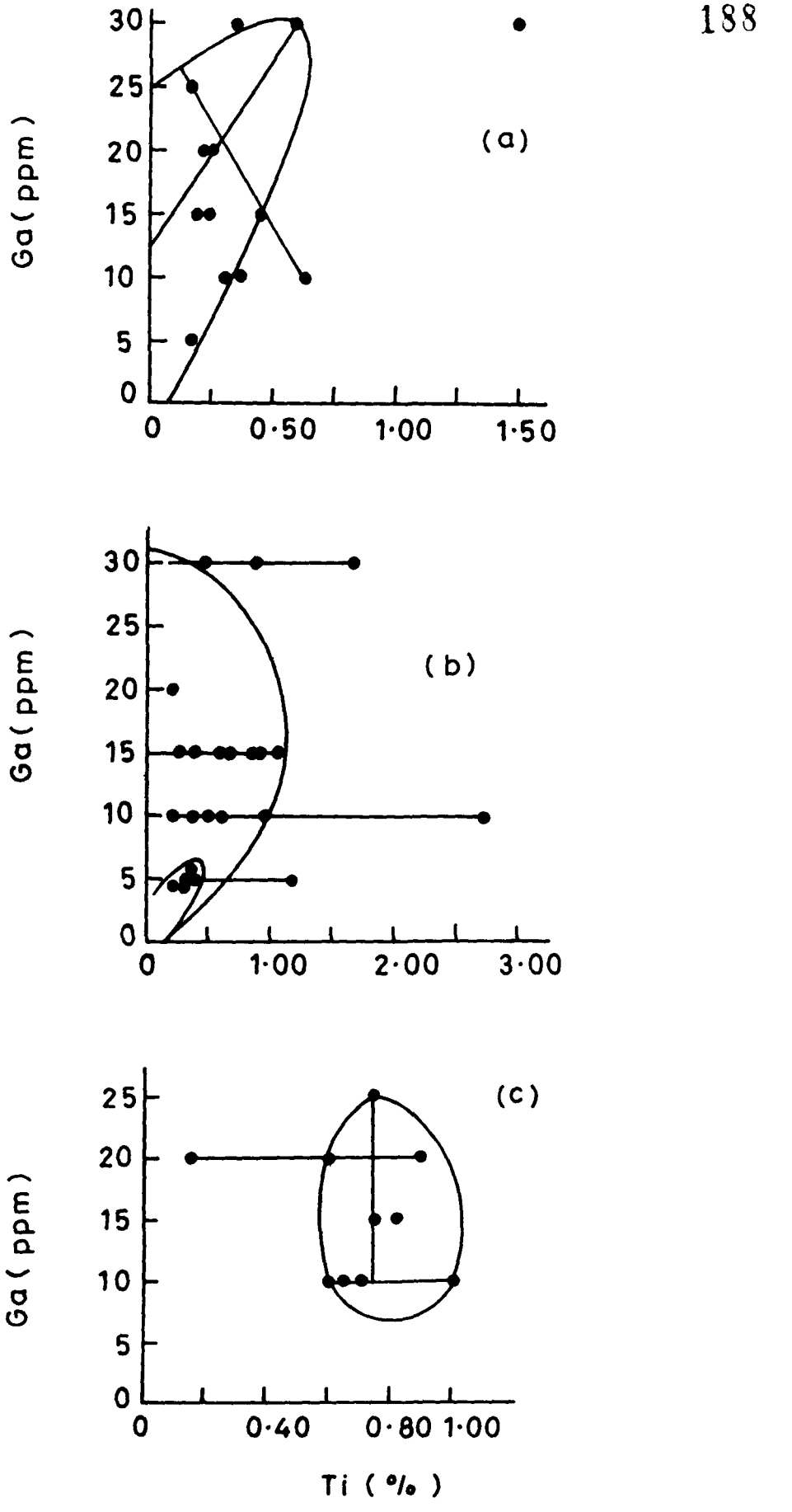


FIG. 47 CORRELATION DIAGRAM OF Ga Vs. Ti IN
(a) LATERITE
(b) BAUXITE

Jagannatha Rao and Krishna Murthy (1980) stated that gallium is generally found camouflaged in aluminium minerals and titatium has a close geochemical affinity with aluminium, results in a sympathetic behaviour between the two in the bauxite profile.

Based on the above, the geochemistry of Shevaroy bauxites, and their inter-relationship with the major and even the minor elements, the following conclusion could be drawn :-

1. The content of trace elements in the bauxite is governed by trace element contents of the parent rock and behaviour of these elements during the process of lateritization. As compared to the Amarkantak or other Trappean bauxites, the Shevaroy bauxite contains less concentration of trace elements because of their poor concentration in the source rock.

2. V, Zr, Cr and Ga show gradual and strong enrichment from the bed rock upwards to the lateritic zone.

3. Ga and Cr show enrichment similar to the concentration of TiO_2 and Al_2O_3, because they occurs either in gibbsite or kaolinite.

4. Maximum enrichment of V was observed in the lateritic zone. The degree of enrichment of both Zr and V is more than the degree of enrichment of Al_2O_3, if one calculates it in terms of percent enrichment from the parent rock to the top of the profile. Al_2O_3 in parent rock is 15.90% and V and Zr 104 and 152 ppm respectively which in the top-most lateritic horizon of the profile comes to 320 and 392 ppm. It shows an increment in Al_2O_3 content as 1.2% and that of V and Zr as 3.07 and 2.5 respectively.

5. Li, Mn, Co, Ba, Sr, Cu, Ni, show depletion upwards in their concentration from lithomargic zone to the lateritic zone. Slight enrichment in the former might have resulted due to local conditions and selective adsorption.

6. Pb, Zn, Sn, Ge, Be, do not show any definite pattern of depletion or concentration. With the advancement in the bauxitization process.

7. Vanadium shows close affinity with Fe_2O_3 because of similar chemical characters.

8. Cr, Ga, V, Zr show a sympathetic relationship with Al and Fe (main constituents of laterites and bauxites) indicate similarity in chemical characters and same trend of concentration during lateritization.

9. Antipathetic and random relationship of Al, with Mn, Ba, Sr is possibly due to the difference in required physico-chemical conditions at the time of precipitation.

10. Ga, Zr, V, Cr, show progressive enrichment and follow the trend of Al_2O_3, TiO_2 and Fe_2O_3 from base upwards to the laterite zone, supports the view of residual or in situ origin.

CHAPTER - VII

GENESIS OF BAUXITE DEPOSITS

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GENESIS OF BAUXITE DEPOSITS

VII.1 : GENERAL STATEMENT :

There is a general agreement amongst the scientists that the processes of lateritization/ bauxitization are the result of sub-aerial chemical weathering under tropical conditions of high rainfall and alternating wet and dry seasons with fluctuating ground water table.

Bauxite is a residual deposit which is formed as a result of decomposition of alumino-silicates and ferro-magnesian minerals of the parent rocks, which results in neo-mineralization of clay mineral (kaolinite), aluminous mineral (gibbsite), iron mineral (goethite) and titanium mineral (anatase), which are resistant to further leaching and solution action.

VII.2 : CONTROLLING FACTORS FOR BAUXITIZATION :

Studies have revealed that not one but several factors are responsible for the genesis of bauxites/ laterites. Some of the important factors are listed below :-

1. Quantum of rainfall.
2. Alternating wet and dry season.
3. Suitable drainage to facilitate leaching and removal of unwanted chemical constituents.
4. Preservation of the bauxite formed.
5. Nature of circulatory ground water, etc.

Levinson (1979), on the other, categorized these factors in the following four groups :-

VII.2.1: CHEMICAL :

1. Original elemental composition and mineralogical character of bed rock.
2. Supergene process responsible for the changes in the mineral composition of the rocks (e.g. pH & Eh).
3. Mobility characteristics of the elements in aqueous and other media in the presence or absence of organic substances.
4. Presence of media capable of precipitating, migration of metals and thus limiting the extent of dispersion pattern.

VII.2.2 : BIOLOGICAL :

1. Vegetation (amount, type and depth of root penetration).
2. Micro-organisms (role in the production of humus, role in oxidation, reduction and concentration of metals.

VII.2.3 : MECHANICAL :

1. Slope angle.
2. Dispersion in surface water (runoff, stream).
3. Dispersion in groundwater (e.g. downward movement of rain water, upward movement by capillary forces).
4. Action of burrowing animals.

VII.2.4 : ENVIRONMENTAL :

1. Climate (e.g. amount and distribution of rainfall, with its resultant effect on the availability of vegetation and on soil formation.
2. Topography.
3. Geological thickness and origin of overburden and hydrological environment.
4. Time.

Nature of proper suite rock is not very much emphasized in the list of above mentioned controlling factors, because it does not play very significant role in the genesis of bauxites. Bauxites could be formed on all kinds of source rocks containing 15% or more alumina (Marbut, 1932; Fox, 1936; Humbert, 1949 and Valeton, 1972). Bauxite deposits in India for example have diversity of parentage, while climate is a blanketed factor, since high temperature and moisture favour decomposition of alumino-silicates and ferro-magnesian minerals and neo-mineralization of secondary minerals (gibbsite and goethite).

Ramam (1978) concluded that the basic laws and operative processes of chemical weathering are similar on a regional scale. The quality and quantity of resultant end product is eventually dependent on the local geological (lithology and structure) and geomorphic environment. Especially the uni-directional and gentle to moderate slope of 4^{o} to 10^{o}, are the most favourable topographic expressions for the development of duricrust of good quality and quantity and emphasized the role of slope in the process of gibbsitization.

West and Dumbelton (1970) observed that the formation of gibbsite requires free leaching of other cations and hence rainfall as well as site conditions are of great significance.

Grubb (1963) emphasized the role of vegetation during the process of bauxitization and stated that lateritization and bauxitization occurs most favourably below thick vegetal cover, with low pH, resulting in the removal of SiO_2, relative to iron and aluminium hydroxides.

Danse (1959) emphasized that the solution and leaching out of iron from weathering profile is greatly accelerated by thick surface humus layers producing complex organic molecules with combined ferrous and ferric hydroxides. These molecules in their colloidal solution would then migrate upward leaving their anaerobic environment and entering in the more altered zone where oxidation of ferrous molecules predominates, together with the formation of insoluble ferric molecules.

Campbell (1917) and Hallsworth and Costin (1953) observed that alternating wet and dry seasons help in the upward movement of sesquioxides resulting in the formation of laterites/bauxites. The zone of fluctuating water table is very much effective in the oxidation and precipitation of iron oxides.

Successive periods of relative dryness and humidity there after resulted in further weathering and erosion of the existing laterites (Pollack, 1980).

It is also observed by a number of workers that the variation in pH results in the variation of physico-

chemical environment of the different zones in the profile, influence the weathering of the bed rock, solution and transport of the material and also the formation of new minerals during the lateritic weathering.

Krishnan (1942) stated that bauxite deposits of Shevaroy hills originates from the alteration of parent rock material under tropical and sub-tropical conditions, resulting in the break-down of the original rock forming minerals and the concentration of the oxides of iron, aluminium and titanium with more or less complete removal of alkalies and alkaline earths.

Aiyengar (1964) and Subramanian and Mani (1980) observed that the bauxites of Shevaroy hills are of lateritic origin, resulted from sub-aerial weathering of charnockites exposed in the area. Lateritization must have prevailed over a large area and the scattered cappings now traced are apparently erosional remnants.

In the present study area, the geomorphological features viz., higher altitude of charnockite in this region and the formation of troughs and horsts may be considered as a vital factor along with climate, vegetation, etc. for the formation of bauxites; since bauxitization is absent in other types of rocks in this region. A stable land surface or a long quiscence period

is one of the essential condition for the process of lateritization and in the preservation of the so formed duricrust.

As mentioned earlier, Shevaroy bauxitic profile is very irregular and there are several square kms of laterite bearing areas that are entirely devoid of bauxites. It is quite likely that the variation in the intensity of lateritization processes and the local variations in physico-geographical and physico-chemical (e.g. pH and Eh of circulatory water) factors might have resulted in selective leaching and differential weathering of the parent rocks. Degree of intensity of leaching also reflects the quality of bauxite which is independent of parent rock textures (e.g. porosity and permeability).

At certain places, bleached bauxite patches in the bauxite layers and laterites of poor quality have also been observed which is an indication and strong evidence of the effect of percolation during rainy season. Percolating water locally leads to remobilization of iron and aluminium at a small scale and hence leaching and redeposition of iron, are the evidences of this process. In this context, these conditions could be grouped into 'primary conditions' - leading to the

bauxite formation and 'secondary conditions' - acting upon the already produced bauxites, either to improve or to deteriorate its quality.

An attempt is therefore being made to infer the role of petro-mineralogical, geomorphological and partly physico-chemical factors in the genesis of laterites/bauxites.

VII.3: STAGES OF BAUXITIZATION :

Parent rocks of the Shevaroy hills have been subjected by weathering and erosion for millions of years. Upon continued weathering, the process of lateritization advances and the rocks undergo near destruction, passing through various stages, which are nicely observed on the slope of the hills during the field investigation. It has provided an opportunity to study the effects of weathering on country rocks and the role of physical, geological, geomorphological and physico-chemical factors governing the formation of bauxite deposits. Hand specimens and thin section studies give a very clear picture as to how continuous weathering registers the change in petro-mineralogical, textural and in the chemical characters of the rocks during the formation of these bauxites.

Krishna Rao, et al. (1976) found four zones of weathering in the Shevaroy hills. Field observations and petrological studies by the author indicate the following successive stages or zones, developed during in situ weathering in a vertical section of a complete bauxite profile.

1. Unaltered parent rock which is overlained by altered or semi-altered charnockites, forming lithomargic clay zone.
2. Aluminous clay zone.
3. Lateritic and aluminous lateritic zone.
4. Bauxite zone.
5. Ferruginous bauxite zone or ferruginous cap.

As observed in the field, the parent rock is followed by an altered or semi-altered zone in which charnockite alters into lithomargic clay, above which pink yellow to brown coloured aluminous clay zone is observed having more alumina content which is overlained by dark reddish laterite, having considerable amount of aluminous minerals and hence termed as 'aluminous lateritic zone'. Locally at some places, this lateritic zone gradually passes into the bauxitic ore body which

is not uniform in thickness and in areal extent. The bauxite with iron encrustations may be termed as ferruginous bauxite, makes the cap of the bauxitic profile, which is comparatively hard in nature and dark brown to reddish brown in colour. Depending upon the intensity of lateritization, thickness of these zones is not uniform throughout the Shevaroy hill region.

The profiles of the different zones are characterized by different physical characters, such as colour, porosity, permeability and compactness, etc.

Table-III shows the presence of various mineral constituents, in the various zones of the bauxitic profile, characterized by different sets of physical and chemical properties.

VII. 3.1 : ZONE-I :

This zone overlies semi-altered or altered parent rocks and indicates the first stage of weathering, which develops an intermediate phase of kaolinite in between the parent rock and laterites/bauxites. In this zone at the beginning of weathering slight obliteration in the fabric of parent rock takes place and primary

silicates are kaolinized and there is essentially a complete removal of more soluble constituents from the mineral structures of feldspars (for example alkalies and alkaline earths). Effect of weathering on ferro-magnesian minerals is not very pronounced. Except the formation of kaolinite from the feldspars, no other neo-mineralization takes place. Replacement and destruction of primary minerals is well observed under the microscope and the clay minerals display a variety of colours (Plate-X, Fig. 2).

VII.3.2 : ZONE-II :

Upon continuous weathering removal of alkalies takes place, which make the media more alkaline in nature. It favours the removal of silica and enrichment of alumina as compared to the first zone. X-ray studies have revealed the presence of kaolinite and traces of gibbsite in the samples of this zone (Table-III). Within this zone, ferro-magnesians start to weather out slightly. Relict quartz grains still survive in this zone but shows little evidence of dissolution. Grain size decreases due to breakage along incipient fractures and sub-grain boundaries.

VII.3.3:ZONE-III :

With the advancement of lateritization process, some of the primary minerals are pseudomorphed by secondary products after complete replacement in this zone. More resistant minerals still survive. Original texture, like banding is characterized by the presence of many sub-parallel bands of dark magnetite (Plate-XI, Fig. 1). The bulk of the material in this zone is yellowish brown to yellowish orange in colour. Hand specimen indicate the development of voids in the replaced mineral structure. Neo-mineralization takes place. Gibbsite and X-ray studies of a few selected sample show the presence of goethite as dominant mineral (Table-III). This zone is characterized by the depletion in SiO_2 content and enrichment in Al_2O_3 and Fe_2O_3 (Table-VII).

VII.3.4 :ZONE-IV :

It is composed of more compact and hard rocks because of physical readjustment such as collapse of mineral relict structure and filling up of the voids with the secondary minerals. Porosity tends to decrease

while specific gravity increases. In this zone process of neo-mineralization reached at maturity. Development of gibbsite, goethite, kaolinite and disseminated grains of anatase are observed under the microscope (Plate-VI, Fig. 2). X-ray studies also reveal the presence of gibbsite, goethite, kaolinite in order of abundance (Table-III).

It has high Al_2O_3 and low SiO_2, besides an enrichment in Fe_2O_3 and TiO_2 content. These rocks are generally of pink and yellowish brown in colour. Compact and earthy varieties of laterites with encrustation of limonite and clay minerals are quite common.

VII.3.5: ZONE-V :

It is the last and the most advance stage of weathering and oxidation, where processes of destruction and replacement reached at maturity. In this zone nearly all Fe^{2+} minerals were found to be oxidized to Fe^{3+} and percentage of iron minerals become appreciable and therefore forms an iron cap over the bauxitic ore body. During alternating wet and dry seasons, iron mobilizes and under the influence of capillary action, its epeirogenic movement takes place and forms hard iron cap in the upper most layer of the profile.

X-ray study indicates that the samples collected from this zone mainly contain hematite, gibbsite and kaolinite in order of abundance (Table-III). The rocks of this zone are reddish brown to dark brown in colour.

In this zone, hematite and boehmite in minor amount have also been observed which are believed to have been formed in the advanced stage of weathering under an acidic environment.

VII.4: FORMATION OF KAOLINITE :

Laterites and bauxites could be formed practically from every type of rock if climate and o other environmental conditions are favourable, but development of kaolinite as an intermediate phase is a function of drainage intensity and pH of the circulatory water. If all the pre-requisites are highly favourable 'direct bauxitization' takes place. Minerals of the parent rock are directly transferred into Al and Fe hydroxide minerals without an intermediate stage of clay formation. If the environmental conditions are less favourable 'indirect bauxitization' takes place with the formation of clay minerals as a first stage and the formation of Al and Fe hydroxide minerals in the second stage.

Allen (1952) stated that the kaolinite is the important unavoidable intermediate step in the lateritization of parent rock to bauxite. The genesis of kaolinite is a process of hydration, which converts the unstable aluminium silicates of crystalline rocks to clay. It is a complex process that acts on complex compounds, mainly feldspars and ferromagnesian minerals and produced clay minerals. The reaction accompanies carbonation and in simplified form can be represented as :-

$$2Al(Na, Si)Si_2O_8 + 2Al(Ca, Al)Si_2O_8 + 3CO_2 + 6H_2O$$

(Albite) (Anorthite)

$$= Na_2CO_3 + 2CaCO_3 + 3Al_2(Si_2O_5)(OH)_4 + 4SiO_2$$

(Kaolinite)

Formation of kaolinite is accompanied by the removal of relatively soluble elements, K, Na, Ca and Mg. An acid environment with comparatively poor drainage, leads to a thorough leaching of Na, Ca, Mg and K as well as many trace elements (Ross, 1943; Reich, 1950; Bates, 1952; Sherman and Uehara, 1956; Keller, 1958; and Grubb, 1969). Goldich (1948)

considered that bauxite is a primary weathering product of bed rock but with a change in weathering conditions, possibly with the establishment of a permanent water table, kaolinite begins to form directly from the bed rock beneath the bauxite.

Kaolinite formation reveals that it is formed either due to low degree of desilicification or because of resilicification of highly resistant aluminium hydrodixe due to poor drainage conditions. The presence of kaolinite in the upper zone of the profile may be due to the resilicification of gibbsite under the influence of acid pH, generated during the dry climate, vegetative action and more over due to the surficial weathering. This fact is observed (by X-ray studies) in many bauxite samples particularly of Hill No. 1, 2 and 4 (Table-III).

Krishna Rao, et al. (1976) studied the weathered samples of second stage from the Shevaroy hills and emphasized the role of pH in the formation of kaolinite. According to them products from mafic rocks are devoid of kaolinite while those from intermediate and garnetiferous rocks contain kaolinite in varying proportion, because of the acidic pH. Formation of gibbsite directly from feldspar or via

kaolinite is largely determined by the intensity of drainage and maintenance of Eh and pH conditions (Kronberg, et al., 1982).

If the drainage intensity is very high and parent rock slope is steep then feldspar is directly converted into gibbsite as represented by chemical equation :-

Feldspar $\longrightarrow$ Gibbsite

$$2H^+ + 6SiO_2.Al_2O_3.K_2O + 14H_2O = 6SiO_4H_4 + 2K^+ + Al_2O_3.3H_2O$$

Mead (1915) considers kaolinite as an intermediate stage in Arkansas bauxites. Allen (1948) favoured a two-stage process, i.e. kaolinization preceding bauxitization.

1. First Step :

Feldspar $\longrightarrow$ Kaolinite

$$2H^+ + 6SiO_2.Al_2O_3.K_2O + 9H_2O = 4SiO_4H_4 + 2K^+ + 2SiO_2.Al_2O_3.2H_2O$$

2. Second Step :

Kaolinite $\longrightarrow$ Gibbsite

$$2SiO_2.Al_2O_3.2H_2O + 5H_2O =$$
$$2SiO_4 + Al_2O_3.3H_2O$$

(Gibbsite)

Sahasrabudhe (1980) noted that an upliftment of water table causes the development of reducing environment below the saturation zone, that reduces the solubility of silica and helps in the formation of clay.

Balasubramanian, et al. (1975) opined that a characteristic sequence of bauxite profile in which lower zone of leaching and upper zone of concretions are suggestive of in-situ weathering. Ramam (1981) while studying the east coast bauxite deposits inferred that the gibbsite-pseudomorphs after the original minerals and lithological gradations of relict foliations in the duricrust are all indicative of their in-situ origin.

From the above discussion and field observations, it could be inferred that formation of Shevaroy bauxite

is a two step process, where desilicification of the underlying kaolinitic clays forms the bauxites. Besides many other evidences furnished below, the presence of intermediate kaolinite phase also supports the theory of in-situ origin.

1. Presence of complete sequence from frésh parent rock to the bauxite ore body having an intermediate phase of kaolinite.
2. Alteration of parent rock strictly follow the trend of its original texture. The relict features such as incipient banding, gradational transition, preservation of parent rock structures, linear bands of aluminous neo-mineralized minerals alternating with ferruginous minerals, etc.
3. The gradational chemical changes from charnockite through lithomargic clays to laterite reflect residual or in-situ weathering of underlying charnockites.

VII.5 : ORDER OF MINERAL STABILITY DURING WEATHERING :

Minerals of the primary environment, are unstable in the secondary environment and consequently

chemical changes take place during weathering in an attempt to reach equilibrium.

Stability of the minerals depend on a combination of factors. It is not only dependent on the type of mineral (structural bonds) and the environment of weathering, but also on factors such as grain size, inclusions, effect of solution on the mineral grains, porosity and permeability of the constituent rock. Many attempts were made to establish the order of stability of silicates with respect to weathering, but no general scheme of mineral stability with respect to weathering may be defined, because some minerals may be stable in one environment but may be unstable in the other. Under the tropical conditions of weathering, almost no mineral is found to be stable.

Goldich (1938) established the order of mineral stability as derived from weathering profiles on gabbroic and granitic rocks and observed that pyroxenes and plagioclases are less stable than K-feldspar. Accordingly, the order of stability is inversely related to the order of crystallization.

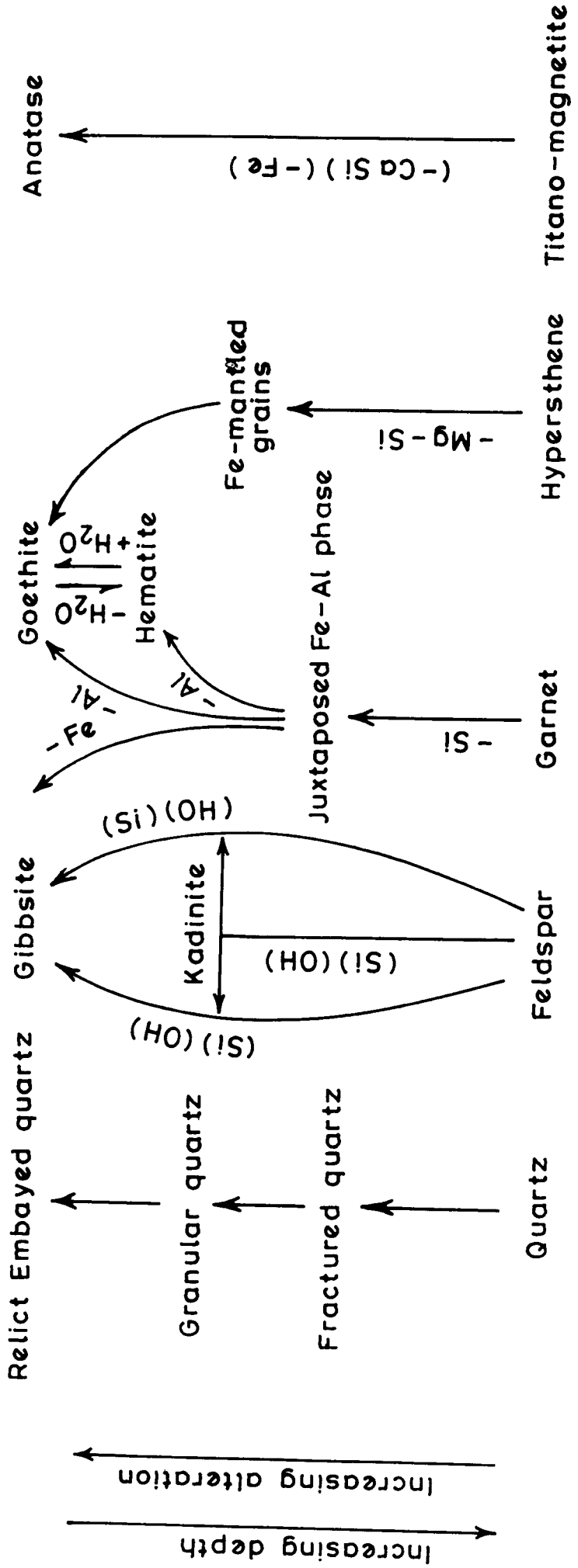
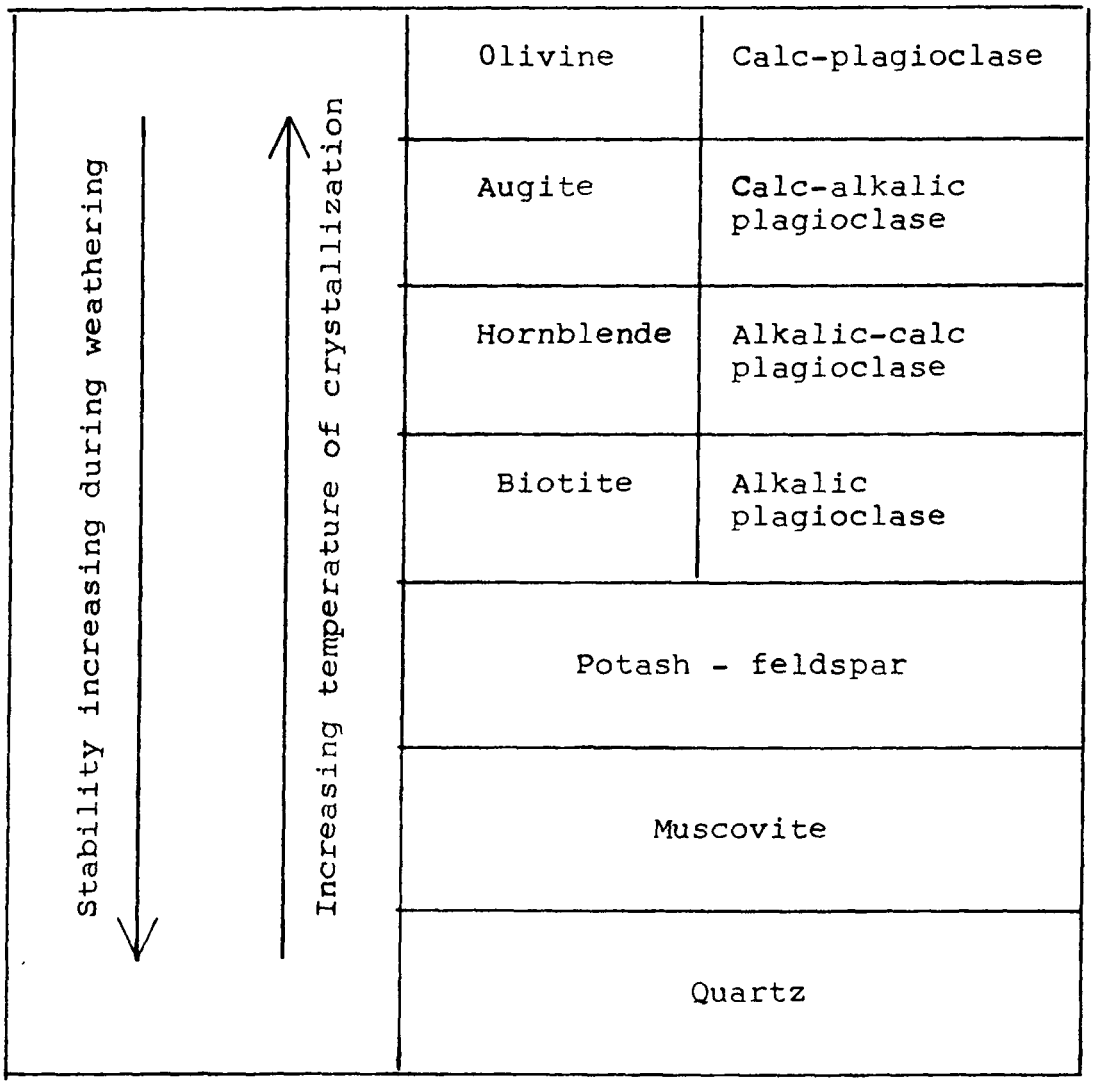


FIG. 48 SHOWING THE PATH OF ALTERATION AND NEOMINERALIZATION TREND OF THE MINERALS

TABLE - V : Represents the relative solubility of common rock forming silicates in chemical weathering, after Goldich (1938).



Goldich (Loc. cit.) series indicates that the minerals crystallized at the highest temperature, under the most anhydrous conditions, are more readily weathered than those crystallized last, from low

temperature and more aqueous magma. As a general rule, the closer the conditions of crystallization approximate to those now prevailing at the earth's surface, the more resistant is the mineral in the weathering environment. Goldich series of stability is also applicable to the some minerals even if they are of metamorphic origin.

Pedro (1964) emphasized the role of pH in mineral stability and Keller (1958) correlated the sequence to the energies of formation of silicate minerals.

Krishna Rao, et al. (1976) established the sequence of mineral stability for the Shevaroy bauxite hills.

Pyroxene=plagioclase=K-feldspar < garnet < quartz

The difference in stability could not be established between K-feldspars and plagioclases and pyroxene with the advancement of lateritization mainly due to the fact that these are pseudomorphed by their secondary minerals.

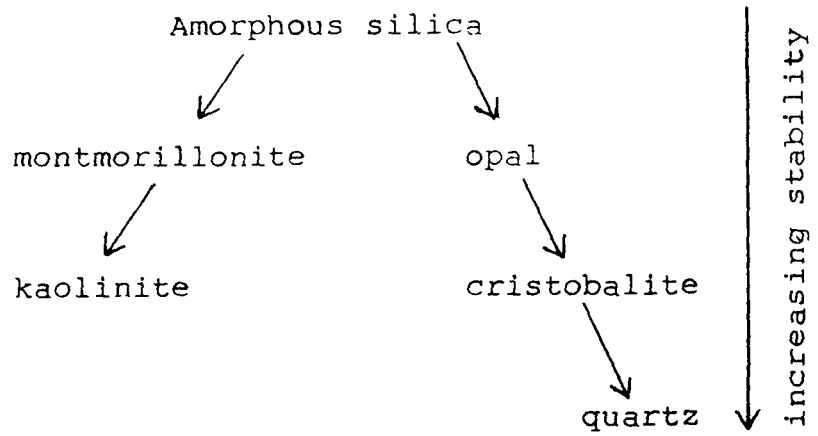
In the study area, the following stability sequence could be inferred with the addition of magnetite which is of common occurrence in the host rock.

Pyroxene=plagioclase=K-feldspar=magnetite < garnet < quartz

VII.6 : MINERAL WEATHERING TREND IN SHEVAROY BAUXITE PROFILE :

Current theories on the disintegration of primary minerals and neo-mineralization are still very tentative. Day by day, evergrowing number of publications are making it more contradictory, because weathering is such a complex process that it can not be equalled under laboratory conditions. Same minerals may show different trends of weathering even under identical environment.

Experimental weathering of various mineral groups has been carried out by many earlier workers in the laboratory. Weathering trend in tectosilicates demonstrated by Correns Von Engelhardt (1938) and Wollast (1963), noticed that SiO_2/Al_2O_3 ratio of the residual layer is governed by pH and it is greatest at neutral pH. Correns (1963) with plagioclase, amphibole and olivine, demonstrated the same principles of dissolution for all tectosilicates. Wey and Siefert (1961) established increasing stability of mineral phases as follows :-



Heydemann (1966) demonstrated that the dissolution of clay minerals is a function of pH. Sapozhnikov (1963) carried out experimental weathering with organic acids upon minerals and stated that all mineral extracts contain noticeable amounts of aluminium dissolved by all acids even at their lowest concentration. The foliation planes, macro and micro joints, fracture and fracture cleavage accelerates the decomposition of primary minerals. Charnockite is the parent rock, alteration of which produces laterite and bauxite, is made up of feldspar, quartz, pyroxenes, garnet (in some cases) and opaques.

Krishna Rao, et al. (1976) studied the trend of primary mineral decomposition and the nature and development of secondary minerals related to the Shevaroy bauxites. In the present study, the process

of mineral decomposition could be enumerated by using petrographical, mineralogical and chemical techniques. Observations of the alteration of individual mineral species provide new information on the lateritization process. The minerals present in these profiles and the mineral weathering sequences as in Figure- 48, resemble to those found in lateritic bauxite deposits in many tropical areas as reviewed by Valeton (1972). These trends also closely resemble to those described by Gilkes et al. (1973), the details of which are given as follows :-

VII.6.1 : FELDSPAR ALTERATION :

Mineralogical and optical studies show that in the first stage of weathering feldspar altered to gibbsite through an intermediate phase of kaolinite under the poor drainage conditions. Folk (1947), Gruner (1949) and Norton (1973) proposed that insufficient alumina favours the formation of pyrophyllite mineral in place of kaolinite under temperature of 300°-550°C. Pyrophyllite quite often occurs pseudomorphically after feldspar and pyroxenes (Deer, et al., 1962).

Ubiquitous dominance of gibbsite mineral indicates very high intensity of drainage conditions under low Eh and neutral pH. Under microscope, plagioclase feldspars appear to be more altered than K-feldspars, but there is no difference in the nature of the secondary minerals derived from the two feldspar (Plate-III, Fig. 2). Irrespective of the nature of the feldspar and weathering products, early stage of feldspar alteration is mainly marked along the structural weak planes in the minerals like cleavages and exsolution lamellae, cracks, and intergrowth structures which serve as conduites for the circulatory solutions. From these planes the alteration extends further into the mineral structure through minor cracks branching into them. Under the microscope the isotropic substances could either be gels of aluminium hydroxide or clay-minerals of incomplete development (Plate-XI, Fig. 2).

In the second stage of weathering with the advancement of alteration the replaced feldspars form dense motted aggregates (Plate-XII, Fig. 1).

The mechanism of mineral break down due to water action has been explained by Jenny (1950). The large euhedral gibbsite crystals suggest its alteration

from feldspar via kaolinite or halloysite and the direct transformation of constituent aluminous minerals of the parent rock to gibbsite indicates the presence of suitable abrasion pH environment of the hydrolyzing system.

Finally, it is observed that feldspar frequently alters first to spherical or parallel needle like oriented aggregates of kaolinite which alters to gibbsite (in some cases feldspar alters directly to gibbsite). Gibbsite is the dominating secondary mineral in the bauxite horizon. Presence of boehmite in a few samples is ascribed to high water pressure, and rapid dehydration of gibbsite (Valeton, 1972).

VII.6.2 : QUARTZ ALTERATION :

During the various stages of weathering quartz show remarkable stability because it lacks in cleavages and other weak planes which serves as conduites for the circulatory solutions. The alteration up to a limited extent is noticed only in the fourth stage of weathering or in the surface horizons resulting in rounded and embayed quartz grains. Size of the quartz grains reduces due to breakage of subgrain boundaries and fractures.

At the advanced stage of weathering the circulatory water containing Al and Fe bearing solutions, initially attacks along the partings and fractures. Due to alteration of grains and subgrains of quartz, the width of cracks has increased as displayed by the larger areas filled by gibbsite and goethite matrix (Plate-XII, Fig. 2). Depending upon the concentration of Al and Fe present in solution, the filling matrix is observed to be either pure gibbsite or pure goethite or an admixture of these in different proportions. Even after alteration of all other primary minerals the subgrains remain angular and fresh in appearance at this stage and can still be recognised under the microscope and in the hand specimen as well.

Quartz does not cleave readily (Deer, et al., 1962) but the common presence of partially healed sub-planar micro-fractures will greatly reduce the strength of grains and may permit disaggregation by relative weak forces (Moss, 1973 and Moss, et al., 1973). Particle size reduction is much more common in polycrystalline and undulose quartz by physical weathering than non-undulose quartz (Blatt and Christie, 1963 and Blatt, 1967).

Quartz is a mineral composed of only Si-O lattice without any other cation. Therefore, it is

replaced only by dissolution and not be decomposition (Krishna Rao, et al., 1976). Silica may be presumed to be released during dissolution in the form of monosilicic acid only, but not as individual Si-O tetrahedral which otherwise would have facilitated the formation of clay minerals after combining with Al and Fe bearing solution.

Beckwith and Reeve (1969) noticed that active and intense dissolution of quartz is favoured by acidic environment in the presence of sesquioxides.

VII.6.3: PYROXENES ALTERATION :

Inosilicates comprises significant portion of the country rock and these are earlier minerals to be leached out. The mode of alteration in the clino and orthopyroxenes is similar and analogous to that of feldspar (Krishna Rao, et al., 1976).

In the first stage of weathering, the mineral alteration is observed. Weak planes, cleavages, cracks and edges, serve as the sites for initial attack. No clay mineral has been identified in these alteration products (Krishna Rao, et al., 1974). But in a few exceptional cases, where kaolinite is the predominant secondary product from feldspars; pyroxene is observed

to give rise to clay of nontronite group. The altered part shows variation in colour and identified as pale brown coloured patch covering the original minerals (Plate-III, Fig. 1). Within this replaced portion, the filling is enveloped by amorphous pale brown or yellowish brown substance more probably of iron hydroxide (Plate-XII, Fig. 2). During the early stage of weathering goethite developed from iron is present in the silicate minerals, latter due to bacterial action and change in pH and oxidizing conditions it is changed into hematite. At the second stage of weathering, altered pyroxenes are pseudomorphosed by goethite. In a few samples of laterite, minute residual grains of pyroxenes are observed, survived as a result of coating around them of clay minerals or due to variation in leaching interstices. Chemical data obtained from the analyses of the parent rocks and that of the bauxite profiles show progressive enrichment of Al_2O_3 and Fe_2O_3 and depletion in SiO_2 content (the concentration of Fe_2O_3 is lesser than Al_2O_3). In general, titanium follows the enrichment trend of aluminium. As discussed later, chemical study of trace elements (i.e. Ga, Cr, Ba, Sr, Cu, Pb, Zn, etc.) also reveal enrichment/ depletion with the advancement in the lateritization process.

VII.6.4 : AMPHIBOLE ALTERATION :

Hornblende is an important mineral of this group found in the parent rock. It is also altered in the same way as the pyroxenes. At the second stage of weathering, decomposition of hornblende produces goethite (Plate-XII, Fig. 2). Although hornblende is a ferromagnesian mineral with OH molecule but there is no marked difference in the process of alteration with the pyroxenes.

VII.6.5 : GARNET ALTERATION :

It is an important constituent of gondites and shows alteration at a later stage. Alteration process of garnet is analogous to that of pyroxenes in all aspects including the secondary mineral development except that it commences at later stage (Krishna Rao, et al., 1976). Alteration takes place from cracks and along the weak planes. On complete alteration the mineral is pseudomorphed by goethite. Presence of gibbsite in mineral structures leads to the supposition that it is also resulted from the alteration of garnet. By oxidation and hydration, the insoluble iron content of garnet is precipitated

as goethite, while aluminium in it is believed to have crystallized as gibbsite. Under the microscope, garnet is an isotropic mineral showing intermediate stage of isotropism and anisotropism, the alteration is depicted by a pale brown coloured zone along the cracks within which forms a dark brown zone (Plate-VI, Fig. 1). These two zones may correspond to amorphous iron hydroxide and crystalline goethite respectively.

VII.6.6 : MAGNETITE ALTERATION :

Magnetite occurs as opaques in the parent rock. Alteration of magnetite produced hematite as secondary mineral. Alteration proceeds by oxidation at grain surface and along cracks so that many highly altered grains consist mainly of hematite containing residual inclusion of magnetite. Alteration to hematite via magnetite, results in an intermediate phase which would be accompanied by a decrease in unit cell dimension (Basta, 1959).

In the light of above, it is inferred that majority of the parent rock minerals through alteration, either produced goethite or hematite except feldspar which altered into gibbsite via kaolinite or halloysite. In some cases garnet and pyroxenes may also produce

gibbsite. The percentage of iron in the bauxites is therefore high as compared to the bauxites derived from the basalts.

According to the presence or absence of various elements in the different weathering zones, they are categorized as the resistant or residual elements that are components of secondary minerals in one group (i.e. Al, Fe, Ti, V, Zr, Ga) and elements that are not retained as components of secondary minerals fall in a second broad group (Sr, K, Ba, Na, Mg, Mn, Ca, Zn, etc.). Silicon does not occur in either group as it is a constituent of the resistant mineral quartz and is also lost from feldspar during alteration of kaolinite, halloysite and gibbsite. Distribution of the major elements Fe and Al in the Shevaroy bauxites exhibit that leaching and relative concentration did not reach such an advanced stage to make it more important economically. The high iron content still found in the bauxite, make it less economic. Downward percolation of rain water leads to remobilization of iron and aluminium locally. During the rainy season, ground water flows through downward percolation while in the dry season, movement of water is effected in the upward direction due to capillary action. With

the change of water table, remobilization and redeposition of iron apparently takes place at a higher level.

VII.7 : REPLACEMENT STUDY OF THE MINERALS :

Thin section study of laterite-bauxite samples and few samples of parent rocks exhibit the trend of replacement and mutual relationship between the feldspar and gibbsite mineral. Replacement of Al by Fe and vice-versa is due to the close ionic radii, which is a type of isomorphous replacement of Fe in goethite by Al and Al in gibbsite by Fe. This replacement may be termed as alumino-goethite replacement. X-ray studies also reveal that the shift of d-values in samples of gibbsite and goethite is attributed to the isomorphous substitution of iron by aluminium (Table-IV). Such type of replacements were observed in the bauxites of India by Valeton (1966) and in the Hungarian bauxites by Bardossy (1966).

The formation of gibbsite from feldspar directly or via intermediate phase of kaolinite depends upon the intensity of lateritization process at different levels in the bauxite horizons.

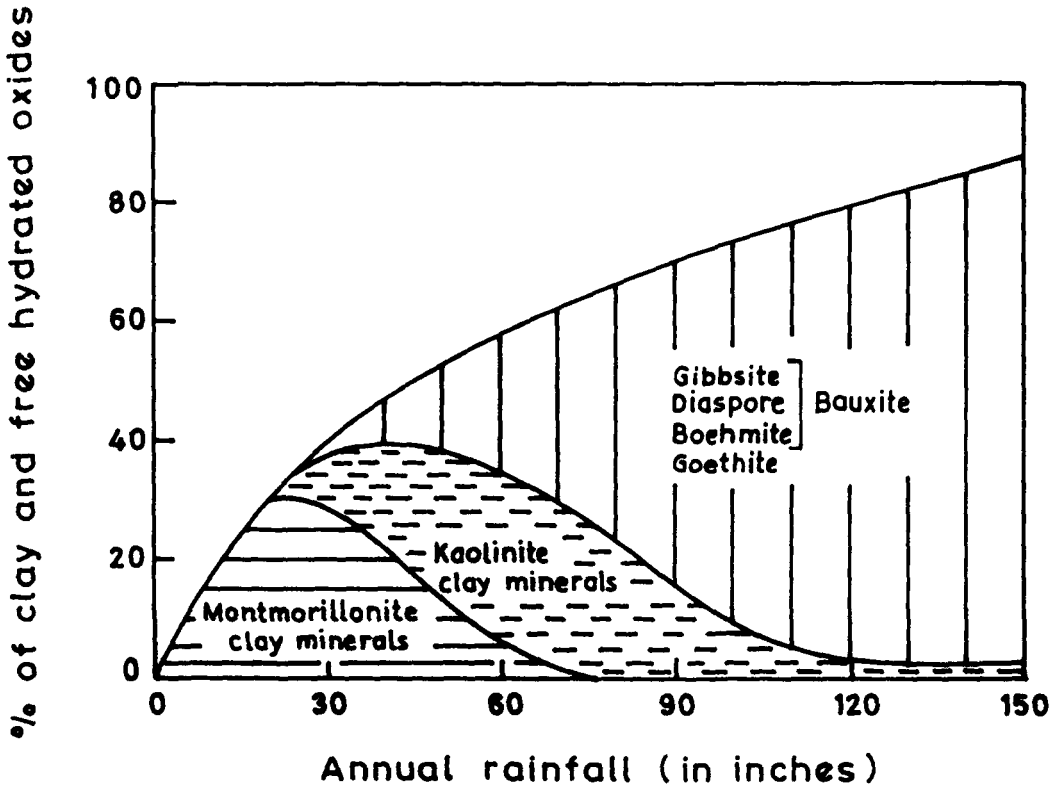


Fig.49 Distribution of clay minerals and bauxites in relation to rainfall.
(AFTER SHERMAN 1952)

Various stages of gibbsite formation from feldspar are observed in thin sections. The prevalent transformation observed in thin sections is the formation of microgranular gibbsite from feldspar along thin veins and veinlets (Plate-XII, Fig. 2). A well known criss-cross pattern of the veins or veinlets is seen, showing the formation of gibbsite. Relict feldspar is also observed as thin patches (Plate-XII, Fig. 1). It thus reflects the formation of gibbsite from feldspar via kaolinite).

VII.8: ROLE OF TEXTURE & DRAINAGE IN THE FORMATION OF BAUXITE :

The litho-textural fabric of the parent rocks may result in the variation in bauxite composition even under identical climatic conditions. Textures are very important for characterizing the complexity of the weathering process - in particular the genetic history. Paul (1966) emphasized the role of permeability and effective porosity in yielding bauxite by leaching of soluble constituents during the process of bauxitization.

Parent mineral structures are instrumental in controlling the accessibility of percolating waters to the bonding cations (Loughnan, 1962).

Allen's (1962) contention that 'permeability' of the parent rock from which bauxite is formed, controls the grade of bauxite.

Ramam (1978) viewed that the gross lithology of the parent rock aided by its 'effective permeability' play a decisive role in steering the intensity and degree of leaching in the chemical weathering. This holds good, provided all other pre-requisite like climate, topography, rate of precipitation, Eh and pH of the circulatory water have acted in their desired equilibrium.

The meagre foliation, limited tectonic openings and general resitance, in view of their massive character of the charnockite rocks, render their 'effective permeability' less intense, there by limiting the extent and thickness of the residual profiles derived from them.

Prasad and Ray (1980) mentioned that the percolatory water circulating obliquely or laterally at shallower depths may facilitate mobilization and migration of iron due to variation in redox potential which is largely dependent upon the level of water saturation and on the water regime of the soils.

The study of configuration of the water table, ground water movement characteristics and distribution

of hydrochemical constituents in relation to ground water movement, indicates that circulatory ground water has played an important role in the lateritization process. Formation of bauxite directly from the country rocks or through an intermediate phase is totally independent of drainage intensity. It is observed that residual deposits were typically formed above the water table whereas below the typical weathering products are the lithomargic clay. Fluctuations in the zone of water table therefore play vital role during the process of bauxitization. The direction and supply of drainage system influences the lateral and vertical facies changes.

Bardossy (1979) stated that bauxites could be formed only if drainage is good. It means that bauxite deposits could be formed above the ground water level or at least in the range of yearly fluctuations.

Bauxitization has been guided predominantly by the lateral movement of leaching solution as compared to the vertical movement due to either poor permeability of underlying horizons or the lack of joint planes. The intensity of leaching and permeability are dependent, to a great extent, on the textural fabric which in turn gives an idea about the structural history of the area. Aleva (1979) believed that the physical characteristics

of the parent rock influence through its porosity and permeability, which directly govern the effectiveness of the leaching process. The rate of weathering of a rock depends on how easily the relative solution could get to the sites of reaction with the body of the rock. This is strictly a function of permeability. The foliation planes, macro and micro joints, fractures and fracture cleavages of the constituent minerals, together accelerate the 'effective permeability', resulting in the decomposition of primary minerals and on the maturity of the bauxite profile.

In the area of study, medium to coarse grained parent rocks have micro-channel ways, following the grain boundaries. Fracturing on both the macro and micro scale, usually results in the intensity and depth of chemical decomposition. There is also a close relationship between relief and drainage which reflects or influenced the distribution of Si, Al and Fe. The pattern of iron removal also indicate the drainage system.

It may therefore be concluded that the bauxite formation is a process of hydration, which converts the unstable aluminium silicates of crystalline rocks to clay. It is a complex process that acts on complex compounds, mainly feldspars and ferromagnesian

minerals and produces a variety of complex clays. Formation of bauxite profile became mature after passing through the various stages of weathering during the process of lateritization. Charnockite —— altered charnockite —— clay —— laterite —— aluminous laterite/bauxite —— ferruginous bauxite are the different stages which could be well demarcated in the field.

1. During the first stage, primary silicates of parent rocks, viz., feldspar and pyroxene were broken down, resulting in desilicification.
2. Formation and migration of clay minerals.
3. Formation of hydrated Al/Fe oxides by intense weathering of silicates and distribution of clays.
4. Mobilization of Fe or Al by organic acids.
5. Gradual enrichment of Al and Fe in the laterites/bauxites, with the transformation of goethite into hematite.

Quantum of rainfall, alternating wet and dry seasons, slope of the area, ground water conditions and vegetation cover are the important factors which played important role in the formation of these bauxites.

CHAPTER - VIII

CLASSIFICATION OF BAUXITE DEPOSITS

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CLASSIFICATION OF BAUXITE DEPOSITS

VIII.1 : GENERAL STATEMENT :

Several attempts have been made to propose a universally acceptable classification of bauxite deposits, but due to manifold features of the deposits, till date no single classification of bauxite deposits is widely acceptable. A number of aspects have to be considered before a widely acceptable classification of bauxites, could be proposed. These factors could be described as follows :-

VIII.2 : CHEMICAL COMPOSITION :

The use to which the bauxite is put is dependent on its chemical constituents, ratio of different major constituents like Al_2O_3, Fe_2O_3, SiO_2, TiO_2, etc., which limits the uses of bauxites. Gradewise, the bauxites may be classified as : metallurgical, refractory, chemical and abrassive grades.

To classify the bauxites/laterites, Fermor (1911) took into account the ratio of (Fe + Al + Ti + Mn) and Si.

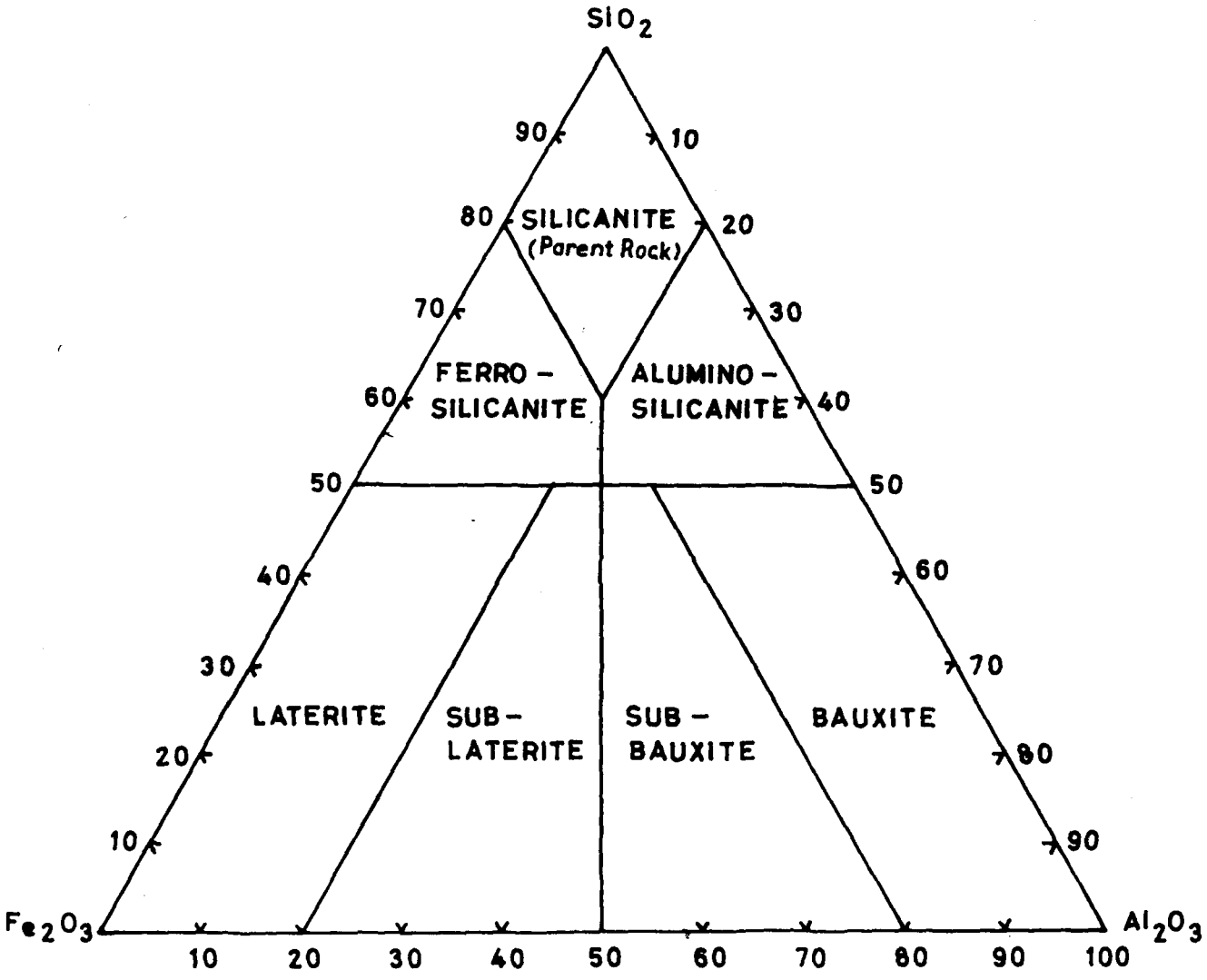

FIG. 50 CLASSIFICATION OF THE LATERITE / BAUXITE PROFILE

(AFTER S.H. ISRAILI, 1977)

Lacroix (1913) introduced the total percentage of sesquioxides as an indicator. Hence material, with more than 90% sesquioxides were considered as 'true laterites', from 50-90% as silicate laterites and from 10-50% as lateritic clay.

Others followed the classifications, based on SiO_2 : $(Al_2O_3 + Fe_2O_3)$ ratio. The terms Ni - laterite, Mn - laterite, Fe - laterite and bauxites are used to indicate relevant metal content, if these resources could be mined economically, the term lateritic nickel ore (nickeliferous laterite), lateritic Mn - ore, lateritic iron - ore and bauxite ore should be applied.

Schellmann (1980) classified the bauxites, by taking into consideration the extent of lateritization which could be measured by (residual) silica content of the samples. The laterite fields are therefore divided into three zones of equal width with decreasing silica content - weak, medium and strong lateritization (Fig. 30).

Silica-alumina ratio i.e. KI index has also been used to classifying the bauxites.

Israili (1977) proposed a classification, based on the proportion of Al_2O_3, Fe_2O_3 and SiO_2 in these rocks. These three constituents have been plotted on a triangular coordinate graph paper (Fig. 50) and an attempt has been

made to classify the various rock units formed under various stages of bauxitization from the varied parent material. Depending upon the parent rock, the various rock units in bauxite profile may be named as follows :-

VIII.2.1 : SILICANITE :

Rock units which contain 65% SiO_2 are termed as silicanite. Al_2O_3 and Fe_2O_3 together forms less than 40%, of the total oxide contents in the rocks.

VIII.2.2 : FERRO/ALUMINO-SILICATE :

Advancement of weathering accelarates mobilization of alumino-silicates and ferro-magnesium minerals and therefore, in these rocks, silica percentage almost equals to Al_2O_3 and Fe_2O_3 put together.

VIII.2.3 : SUB-LATERITE/SUB-BAUXITE :

Further enrichment of either Fe or Al with gradual depletion in SiO_2 contents in succeeding horizon is termed as sub-laterite or sub-bauxite, depending upon the concentration of Fe or Al.

VIII.2.4 : SILICEOUS-BAUXITE :

In these rocks, silica percentage becomes appreciable because of the resilicification and therefore termed as siliceous bauxite.

VIII.2.5 : LATERITES OR BAUXITES :

Under this category, the content of iron and alumina, reaches up to 60-65% of the total bulk composition.

VIII.2.6 : ALLITE :

The term allite has been proposed for those aluminous materials which are extraordinarily high in alumina content (Aluminium 67%). All other contents together remains below 35% or even less.

VIII.2.7 : FERRALITE :

Deposits which are prominently composed of hydroxides of iron, which constitutes the bulk composition, exceeding 67% or more in some cases are termed as ferralites.

VIII.3 : ORIGIN & MODE OF OCCURRENCE :

As mentioned earlier, the bauxite deposits have diversity of parentage and of variable nature and mode of occurrences. Harder (1952) proposed the following classification based on parent rock composition.

1. Deposits derived from alkali and aluminium rich silicate rocks.
2. Deposits connected with limestones.
3. Deposits connected with sedimentary clays.
4. Deposits connected with intermediate and basic eruptives.
5. Deposits due to the vigorous weathering of rocks of medium aluminium content.

Valeton (1972) developed another classification based on the rocks underlying the deposits.

1. Bauxites deposits overlying igneous and metamorphic rocks -
   a. Slope type.
   b. Plateau type on basic igneous rocks.
   c. Plateau type on variable rock types.

2. Bauxite deposits on sedimentary rocks -

a. Bauxites on clastic sediments.

b. Bauxites on carbonate rocks.

c. Bauxites on phosphatic rocks.

Patterson (1967) proposed the classification, chiefly concentrating on depositional features (which are not considered by Harder and Valeton).

1. Blanket Deposits :- flat-lying layers of variable thickness.
2. Interlayered Deposits :- discontinuous layers.
3. Pocket Deposits :- filling of depressions.

Another classification proposed by Grubb (1973) is based on the altitude at which bauxitization has taken place.

1. High level or upland deposits
2. Low level or peneplain type deposits.

Under this classification, he also considered the role of water table in the genesis of bauxites instead of parent rock composition.

Based on the mode of occurrence, the bauxites are classified as follows :-

INTENSITY DISTRIBUTION OF BAUXITE FORMATIONS Vs TIME
(AFTER BARDOSSY)

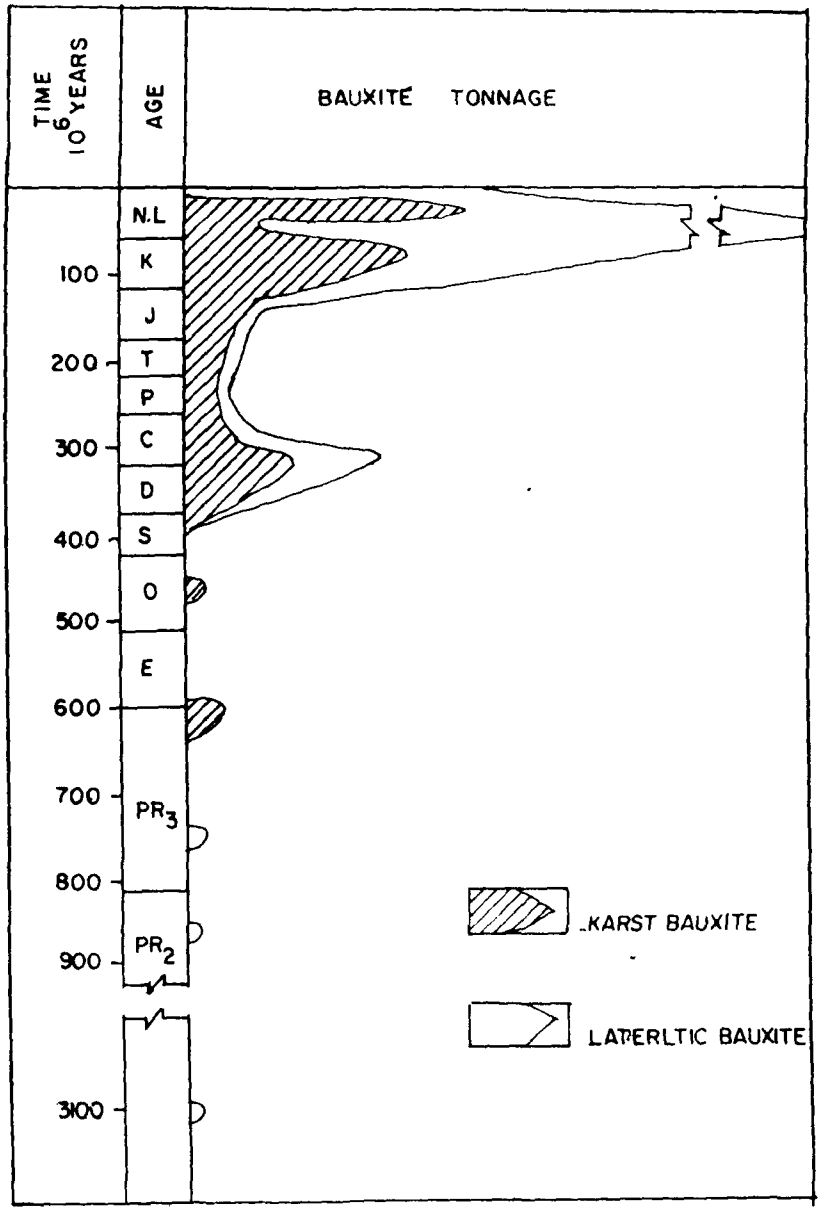

FIG. 51

1. Blanket type :- e.g. Galikonda bauxite deposits in A.P.
2. Lensoid type :- e.g. bauxite deposits of palni hills in T.N.
3. Pockety type :- e.g. bauxite deposits of Amarkantak in M.P.

Valeton (1972) also divided bauxite deposits into two groups on the basis of facies catena.

1. The bauxite on plateaus of Deccan-peninsula are the Indian examples.

   a. The slope type (gibbsite type) e.g. bauxites on plateaus of the Deccan-peninsula.
   b. The plateau type (Gibbsite-boehmite type) e.g. bauxites of southern India occurring on charnockites.

The intensity of formation of various bauxites in relation to geologic time scale comprehensively summarized by Bardossy (1979) as shown in Figure-51.

According to him out of the 34 billion tonnes of global bauxite reserves estimated, 85% constitute lateritic type, 14% Karst type and 1% Tikhvin type.

On the basis of depositional features, mineralogic and petrographic characters, Bardossy (1979) classified bauxites into three categories -

1. Laterite-bauxite deposits
2. Karst-bauxite deposits
3. Tikhvin-type deposits.

VIII.4 : MINERALOGICAL COMPOSITION :

It is one of the most applicable bases of classification. Three important minerals of bauxites are well known, namely gibbsite, diaspore, and boehmite. On the basis of their percentage in a given sample of bauxites and presence of other associated minerals viz., hematite, goethite, quartz, magnetite, titanium, etc. Bardossy (1963) described the following mineral groups found in association of bauxites.

1. Allitic minerals :- Gibbsite, boehmite, diaspore and corundum.
2. Clay minerals :- Kaolinite group with illite and montmorillonite group.
3. Clastic minerals :- Quartz, heavy minerals, ore minerals.
4. Ferritic minerals :- Hematite, goethite, maghemite and magnetite.

PROPOSED CLASSIFICATION OF BAUXITES AND ALUMINOUS IRON ORES AND CLAYS
(AFTER VALETON 1972)

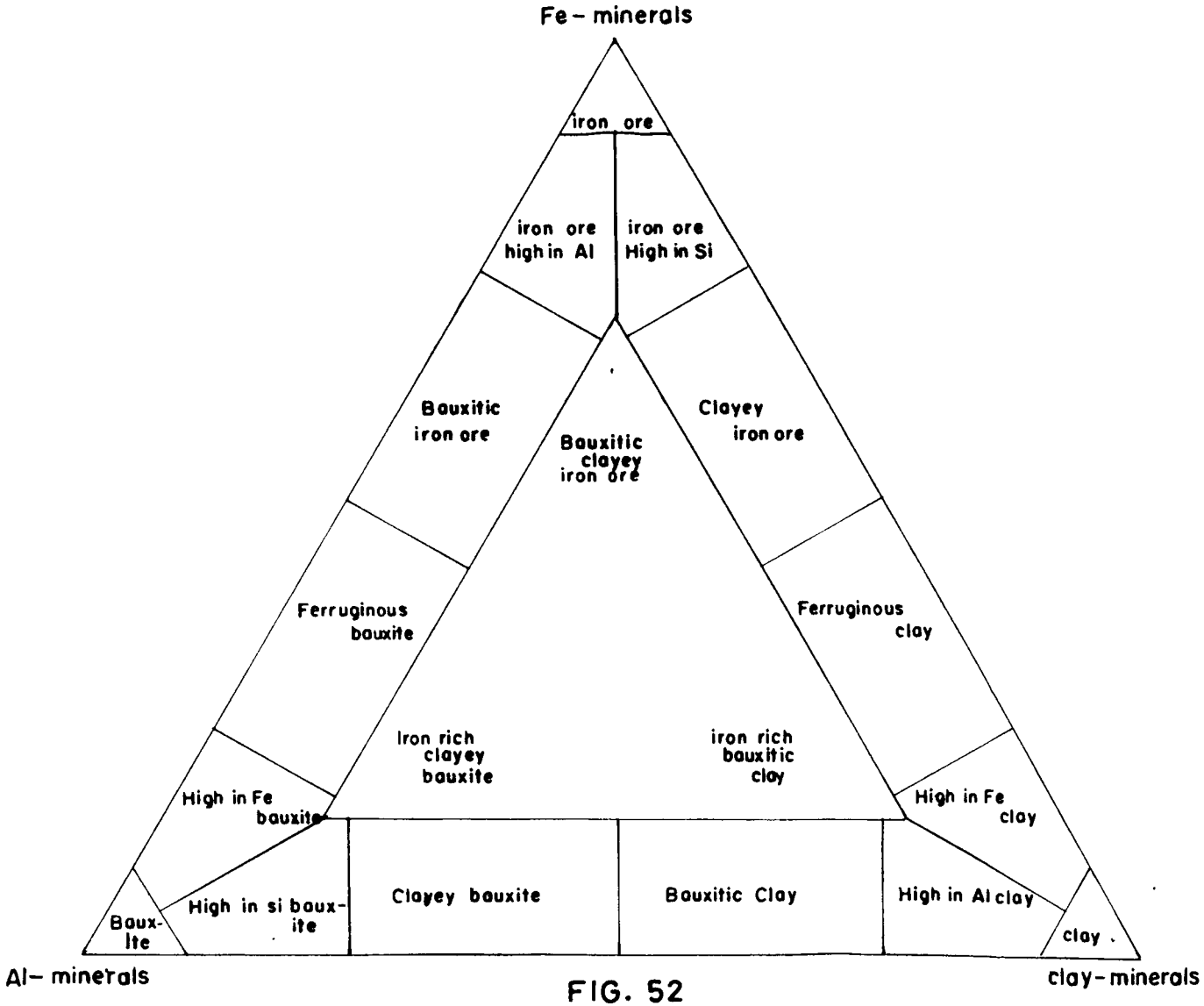

FIG. 52

Figure-52 shows the various type of bauxites as proposed by Valeton (1972) and modified by Bardossy (1963).

This triangular classification with Al-minerals, Fe-minerals and clay-minerals on three apices have become more simple after petrographic studies of the thin sections of bauxites from various horizons.

VIII.5 : TEXTURAL CHARACTERS :

Various classifications have also been proposed taking into account the main variation in textural features of bauxites and associated rocks of the profile. Development of textural types, depends upon the nature and type of source rocks. Valeton (1972) described the various textural terms found in bauxites.

VIII.5.1 : UNLITHIFIED ROCKS :

For example red earths and loams. Both of them reveal relict textures and textures of neo-mineralization that are difficult to distinguish in these rocks.

VIII.5.2 : SOLID ROCKS :

The textures of which have withstood even on

weathering. The texture may be divided into relic textures of the source rocks and textures formed during neo-mineralization. On the basis of textural variations, bauxites may be classified as follows :-

Skeleton bauxite, cellular bauxite, earthy bauxite,etc.

The bauxites of the study area reveal characteristic textural features which indicate that parent rocks have played a significant role in their formation. For a comparative study, an attempt has been made to correlate these textural attributes with the other important bauxites formed on a different rock suite.

a. STUDY AREA BAUXITES :

These bauxites have been formed over the charnockite group of rocks. Texturally the residuum derived from charnockite show very dense and massive spongy texture of gibbsite in the study area.

In the east coast bauxite deposit on the other residuum derived from khondalite parentage are characterized by typical vesicularity and cavernous nature.

b. DECCAN-PLATEAU BAUXITES :

Texturally this residuum has been derived from

basalts and has developed a typical pisolitic and oolitic texture.

VIII.6 : GEOLOGICAL AGE :

Bauxites could also be classified according to their age of formation. Bauxite deposits of various kinds are knwon to have formed throughout the earth's history. In most case they have been eroded away, but bauxite sediments which surround the fossil plateaus prove their original existence. The oldest larger bauxite deposits so far observed occur in Early Palaeozoic Sediments.

Numerous workers studied the age of different bauxite deposits by constructing the planation surfaces (Selby, 1971; Vaidyanathan, 1967; Mc Farlane, 1976; Valeton, 1972; Bardossy, 1973, 1979 and Subramanian and Murty, 1976). In the absence of datable sediments overlying the cappings, it has not been possible to find the exact age of laterite/ bauxite. Subramanian and Murty (Loc. cit.) gave a concept on the age of bauxites which is based on the long term ageing of gibbsite (trihydrate) into boehmite and diaspore (monohydrate). On the basis, it has been postulated that gibbsite (trihydrate) is probably the first aluminium mineral to crystallize and then transforms into boehmite

(monohydrate) and thence to diaspore with the passage of time (Clayton, 1969).

It has been observed that despite the occurrence of all the three minerals in several deposits, there is a dominance of diaspore in palaeozoic rock, boehmite in mesozoic and gibbsite in tertiary rocks.

Bauxites of Jammu and Kashmir is diasporic and are therefore considered to be of palaeozoic age.

Nilgiri bauxite which is contemporaneous to Shevaroy bauxites, is also considered to be of Tertiary age (Subramanian and Murty, 1976). Since Tertiary represents a long span of time, an attempt has to be made to narrow down the limits of the age of the laterites on the plateau.

Bardossy (1979) stated that most of the bauxite deposits were formed during the Palaeocene and Eocene in Indian Peninsula.

According to Vaidyanadhan (1967) the plateau landforms on the Shevaroy and Kollaimalai hills are of middle Miocene age. It is but natural to conclude that the laterite cappings now traced on these plateau landforms would have formed at least from Palaeocene onwards because evidence on record reveal a warm and humid type of climate conducive for lateritization was prevalent in the peninsular from the beginning of Tertiary. It is but reasonable to

accept that originally laterite should have been much more extensive and thicker than they are now. They would have occurred as large blankets on all the plateau landforms, forming an integral and conspicuous part of landscape in the past geological ages. Like all other crustal rocks, the later blankets would have been subjected to post-formational modifications including weathering and erosion. The present cappings are therefore the erosional remnants.

Selby (1971) believed that the formation of laterite is confined to the Koppen's 'A' climate zone, a belt of 30^{o} on either side of the equator. Major part of the Indian peninsula falls well within Koppen's 'A' climate in which the formation of present day laterite is confined, but a solution has to be find out as to whether the formation of all residual laterites is to be related to the present day climate alone or whether the climate of past geological ages also were conducive for laterite formation. Bardossy (1973) to solve this problem, analysed the trend of bauxite formation on a global scale from the plate tectonic view point and suggested that formation of lateritic bauxite in the Indian and the African plates could have commenced in upper Cretaceous and continued in Tertiary. The above view point was also strengthened on the bases of palaeontological evidences and global models of palaeo-weather patterns and palaeo-geography by numerous workers

(Krishnan, 1968; Sahni and Kumar, 1974; Frakes and Kemp, 1972 and 1973 and Ramanujan, 1968).

Fox (1923) opined that possibly no lateritization began in Indian peninsula until a monsoon climate was established i.e. at the close of Mesozoic era (Cretaceous period). Based on the points highlighted above, it is reasonable to mention that climatic conditions conducive for lateritization processes were prevalent at least from Cretaceous onward.

Subramanian and Mani (1979) mentioned that the surface with bauxite and bauxitic clay on the west coast is correlatable with the plateau landforms with laterite bauxite cappings on the Nilgiri and Palni hills and considered Pre-Mio-Pliocene age for them. Valeton (1972) observed that bauxite formation has wide geographical range on a global scale and that some deposits in India, including those trace on charnockitic rocks in the Indian peninsula, are of Eocene age. Based on this observation, the Pre-Mio-Pliocene Lateritic bauxites on the Nilgiri and the Palni hills may be considered to be of Eocene in age.

A meaningful solution regarding the age of bauxites may result if all the 'fossil' laterite cappings in the peninsula are brought into a single ambit of studies. Since the plateau landforms on the Shevaroy and Kollaimalai hills are thought to be correlatable with the Nilgiri-Palni

GENERALIZED EAST-WEST CROSS SECTIONS ALONG 10° 15'– LATITUDE AND 11° 25' LATITUDE IN THE PARTS OF SOUTH INDIA

SCALE

VERTICAL 1: 134, 000 (Approx)

HORIZONTAL 1: 5,000,000 (Approx)

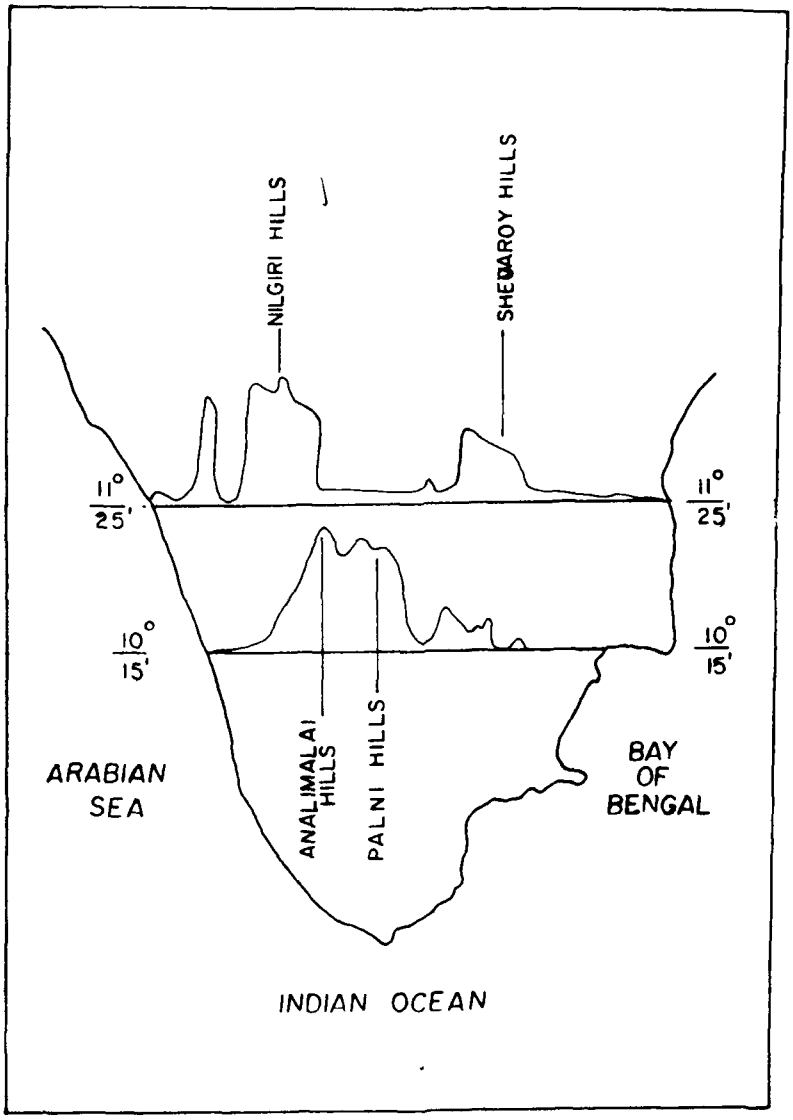

FIG. 53

surface, may also prove Eocene age of the lateritic bauxite on the Shevaroy hills (Fig. 53).

Finally, the period of bauxite formation and bauxite deposits formed throughout the geological time could be classified as follows :-

1. Bauxite deposits of Palaeozoic era.
2. Bauxite deposits of Mesozoic era.
3. Bauxite deposits of Tertiary era.

In which themost important world wide deposits are of Eocene age which fall under Tertiary era.

From the foregoing discussion, it may be concluded that the bauxite deposits are classified on the basis of chemical and mineralogical composition and the deposits having similarity in origin and mode of formation are classed separately.

In general, chemical, petro-mineralogical, genetical and geological (age) are the important bases used in the classification of the bauxite deposits :-

BASES OF CLASSIFICATION :

1. Chemical Composition :

Ratio of major constituents like Al_2O_3, Fe_2O_3, SiO_2, TiO_2, etc. major impurities and uses of the ore according to the grade.

2. Origin and mode of occurrences :

Parent rock composition, intensity of lateritisation, allochthonous, autochthonous, high level and low level deposits, blanket type, lenticular type, pockety type and facies variation.

3. Mineralogical Composition :

Gibbsitic, boehmitic, diasporic, allitic, etc.

4. Textural characters :

Skeleton, pisolitic, non-pisolitic, vesicular, cavernous, etc.

5. Geological Age :

Palaeozoic, Mesozoic, Tertiary or Cenozoic bauxite deposits.

Quality and quantity of the different bauxite deposits are therefore mainly dependent of the degree and intensity of lateritization and also upon the geomorphological and physiographical features of the terrains.

VIII.7 : CLASSIFICATION OF SHEVAROY BAUXITE DEPOSITS :

In the light of the above discussions, the bauxite deposits of the study area could be classified as under :-

The bauxite deposits of Shevaroy hills are of highly variable nature and composition, it is therefore difficult to classify them properly without taking into consideration, the various bases of classification. The classification proposed by Israili (1977) could be adopted to solve the problem in question up to the maximum extent and from the view point of academic interest. He represented the various stages of bauxitization by proposing the terms laterite, sub-laterite, bauxite and sub-bauxite, according to the different chemical composition, concentration or removal of the major oxides in the bauxite profile, determines the grade of bauxite ores, and also reflects the role of pH and Eh of the circulatory waters, the intensity of the drainage, vegetation cover and fluctuating water table etc. during the process of weathering.

Depending upon the concentration of Fe or Al and Si, the terms Ferro/alumino-silicate and sub-laterite/ sub-bauxite may be used for the Shevaroy bauxite deposits (Figs. 31 & 50).

Other bases of classification also depend upon the intensity of lateritization and mode of occurrences. Based on the rock underlying the deposits, Shevaroy bauxite deposits overlying the igneous and metamorphic rocks which are of lensoid or lenticular in nature. These deposits are smaller in areal extent and in thickness of the profile because of the selective and non-uniform leaching. Based on the altitude at which bauxitization has taken place, these are high-level or upland deposits which are formed by residual weathering above the ground water table and under poor drainage conditions. On the basis of facies changes these deposits are of the slope type (gibbsite type). It forms lense-shaped bodies on the slope. It does not develop a typical vertical profile, and does not form large and important deposits. Because of its morphological exposure, they may be fossilized only if are rapidly covered by younger sediments. Gibbsite is the main aluminium mineral under the good drainage conditions on the slope of the plateau, direct transformation of gibbsite from feldspar is expected, otherwise via an intermediate phase of kaolinite.

Valeton (1972) also observed the facies differentiation in a single laterite profile, laterally as well as vertically, which is caused due to the movement of iron

and alumina. In the present studies such facies variations are well observed, and the author opined that the facies variation or movement of iron, alumina and silica is influenced or controlled by the pH of the media and intensity of drainage. It is further believed that the presence or absence of kaolinite as an intermediate phase between the bauxite ore body and parent rock is a function of drainage intensity. The presence of comparatively higher concentration of alumina in scarp sections is attributed to optimal drainage conditions and therefore placed these deposits in the 'Kaolinite-gibbsite' facies.

Mineralogically it contains allitic clay and Ferritic minerals throughout the bauxite profile.Texturally, it can be classed under the category of skeleton bauxite, which is characterized by the preservation of micro and macro-fabrics of the source rocks even on weathering. These deposits are classed into two groups due to relative enrichment or less soluble constituents,having gel-like textures of two types, viz. :-

1. Dense texture in the negligible pore space.
2. Spongy texture with high porosity.

As discussed in detail under the head of geological age of bauxite deposits, it has been cleared that the Shevaroy bauxite, on the basis of correlatable

planation surfaces could be considered of Pre-Mio-Pliocene (Eocene) in age. Petro-mineralogical studies also reveal that the Shevaroy bauxites which are predominantly composed of gibbsite, may be ascribed to Tertiary age.

VIII.8 : COMPARATIVE STUDY OF DIFFERENT INDIAN BAUXITE DEPOSITS :

In India, the bauxite deposits have diversity of parentage. The bauxites derived from basalts are more extensively studied and being widely used for industrial purpose, as compared to the bauxites derived from Khondalites and Charnockites - mainly in the southern part of India. The bauxites of different parentage show a wide variation in grade as well as in the physical characters such as textures, hardness, structures, etc.

In the southern part of India even the bauxite deposits of the same parentage show a marked variation in chemical quality, texture, thickness of the complete profile, etc. Shevaroy bauxite deposits of Tamil Nadu and East Coast bauxite deposits of Andhra Pradesh and Orissa are the important examples, to note the important variation features.

In the light of previous literature, it has been found that the Eastern Ghats which constitute a major

physiographic province in the Indian peninsular shield are essentially made up of rocks belonging to the Khondalite and Charnockite groups, which shows marked variation in elevation and slopes, etc. Bauxites occur both on Khondalites and Charnockites, their frequency, however, is more on the former.

Morphologically speaking, the terrain in which the duricrust derived from Khondalites exhibit either polydirectional or unidirectional, moderate to steep slope. The terrain is relatively flat top of gently undulating where the source rock is charnockite. The Khondalites occupy relatively higher elevation and the Charnockites are confined to the lower levels, where-ever they are juxtaposed.

The bauxite profile derived from Khondalites, not only have vast areal spreads and sizeable thickness, but they are also better in quality than those derived from the Charnockitic rocks (Ramam, 1976). This is due to the fact that feldspar, sillimanite and garnet are the integral constituent minerals in Khondalite and cumulatively contribute to the formation of gibbsite. While it is only the feldspar that gives rise to gibbsite in Charnockites, therefore alumina percentage, is higher in Khondalitic derivatives. Similarly in the case of Shevaroy bauxite deposits the host rocks include charnockites and leptynites, give rise to the low grade bauxite deposits.

Bauxites of northern or central part of India, whose parentage are basalts also differ from the bauxites of South India (particularly Shevaroy bauxites deposits which forms the part of present investigation) in contents of silica, alumina, titanium and are devoid of typical pisolitic or oolitic textures. The bauxites derived from basalts in the central or northern India are considered to be of better quality due to more alumina content and less free silica. On the other, the bauxites of the study area are not of good quality, as they contain comparatively less alumina and more free silica and iron, hence they are generally termed as aluminous laterites rather than bauxites.

It is interesting to note that bauxites from the Shevaroy hills are blended with high grade ore from Madhya Pradesh and Gujarat and then utilised for aluminium extraction in the plant put up by MALCO Ltd. at Mettur, district Salem, Tamil Nadu. It is reported that at Mettur, bauxites having 44 - 52% Al_2O_3, 25% Fe_2O_3, 1.07% TiO_2, and 10% SiO_2 (of which reactive silica is limited to 3%) are utilized.

It is suggested that the poor quality of Shevaroy bauxites is mainly due to subsequent leaching and relative accumulation of aluminium which did not reach such an advanced stage as in the other areas. High iron content

still found in these bauxite, is one of the reasons in considering this deposit of lesser economic importance.

Plate-XIII, Figures-1 & 2; Plate XIV, Figures-1 & 2, show the characteristic textural and structural features of Shevaroy bauxites discussed here.

The similarities and differences in the bauxite deposits of central or northern parts with that of southern part of India are briefed as follows :-

Properties	Bauxites of central or northern India)	Bauxites of southern India
1. Parent rocks	Basalts	Charnockites, Khondalites and leptynites.
2. Colour	Pink, cream and white to brown	Red, dark-brown to black and earthy yellowish material in cavities. Yellowish brown on the scarp faces.
3. Texture	Pisolitic, oolitic and vesicular.	Vesicular, cavernous, spongy and massive.
4. Structure	Relict vesicles of basalts are rarely seen.	Palimpsest texture showing banding or gneissosity of parent rocks easily recognizable.
5. Degree of Hardness	Relatively medium to soft	High in the major part of profile, except only at scarp faces.

Properties	Bauxites of central or northern India	Bauxites of southern India
6. Specific gravity	Medium to low and varies with the concentration of Al & Fe (2.3 to 4.28)	Because of the high iron content, medium to high (2.5 to 5.3).
7. Ferruginous cap or iron crust	Hard, but of negligible thickness or absent	Very hard and possess remarkable thickness.
8. Porosity	High and varies with the intensity of weathering which is a reflection of parent rock texture	Relatively medium to low because of the dense and more compact nature of parent rocks.
9. Clay contents	Rarely occurs, only found in the channel ways	In the earthy and vesicular bauxites, the cavities are filled up by clay or kaolinite material.
10. Mineralogy	Gibbsite and cliachite are the important aluminous minerals and crystalline variety of gibbsite is quite common	Mainly gibbsite which is fine grained and dense in nature, very rarely boehmite.
11. Transition zone	In between parent rocks and bauxites, duricrusts a transition zone of lithomargic clay is quite common except on the slopes	Transition zone is also present in the case of charnockite parentage but in the Khondalite derivatives lithomargic clay zone is almost absent.

Properties	Bauxites of central or northern India	Bauxites of southern India
12. Thickness of the profile and areal extent	Relatively attains more thickness and covers a vast area	Thickness varies from place to place because of the dense nature and variability of the parent rocks. Intensity of weathering is not so frequent and hence covers a limited area.
13. Mode of occurrence	Generally occurs as blanket type deposit and very rarely pocket and lensoid type, occurs relatively on low level plateaus hence termed as 'low level bauxites	Lenticular or lensoid type of deposits are often found and generally on high level plateaus, hence called 'high level bauxites' except East Coast bauxite.
14. Average chemical composition of bauxite (not included laterite)	Al_2O_3 40-60%	39-61%
	Fe_2O_3 2-20%	5-32%
	SiO_2 3-5%	3-8%
	TiO_2 3-9%	1-5%
	LOI 21-32%	18-30%

CHAPTER - IX

SUMMARY AND CONCLUSION

CHAPTER - IX

SUMMARY & CONCLUSION

The Shevaroy hill bauxite deposit lies in between N11°48'17" to 11°50'31" and E78°14'03" to 78°72'53" around Yercaud in Salem district of Tamil Nadu State and attains an elevation of over 5000 feet above M.S.L.

These bauxites were residually derived from the underlying charnockite suite of rocks under the tropical or subtropical conditions. Study of the bauxite profile revealed that fresh charnockite is followed by an altered zone and lithomargic clay at the base to the laterite at the top (Fig. 3).

Field observations revealed that lateritization on these hills is neither uniform nor universal, but is only confined to certain lenses and zones. The deposits occur as lenticular in shape. The base of the deposit is extremely irregular and therefore thickness of the profile varies from hill to hill in the study area. In general, the bauxite is of earthy type, mixed with silica, devoid of pisolitic and oolitic structures.

Generally, the bauxite is of lateritic type as it contains higher proportion of iron. Mineralogical studies revealed the presence of gibbsite, goethite, kaolinite as the major constituents and quartz, anatase, hematite, boehmite as minor. Limonite occurs as cavity fillings. Variscite-ferrian, a new mineral has also been investigated during the present investigations from top-most lateritic zone of the Hill No. 2 (Table-III).

Petro-mineralogically, each zone of the bauxite is characterized by a definite set of mineral assemblages and their textural characters. On an average, the bauxite is cavernous, vesicular and earthy type, characterized by the presence of irregularly shaped channels or passage ways, stimulating veins or vein like structures. Following mineralogical variations in the bauxite profile from base upwards were observed :-

1. Decrease in kaolinite, quartz and goethite content.
2. Increase in the gibbsite content, possible due to substitution of Al in goethite.
3. Decrease in gibbsite content, because of the replacement of goethite by hematite in the top-most layer.

Bauxitization or lateritization is a process of weathering, which could be considered as the tropical disease of the rocks under favourable conditions viz., quantum of rainfall, alternating wet and dry season, suitable drainage and nature of circulatory ground water, etc. All kinds of parent rocks could produce laterites and bauxites, if these conditions prevail under tropical or subtropical weathering.

Five successive stages of weathering have been observed in this profile. Each is characterized by definite set of minerals and their physical and chemical characters such as, colour, hardness, compactness, porosity, permeability and chemical composition, etc.

Presence of complete and characteristic sequence from charnockite to the laterite/bauxite with an intermediate phase of kaolinite and retention of original parent rock textures there-in, support the theory of in situ or residual weathering of the underlying charnockites.

The weathering trend study of the minerals present in the rocks of the charnockite suite, made possible a sequence of mineral stability as follows :-

Pyroxene - plagioclase - feldspar - magnetite - garnet and quartz in the end.

Feldspars, pyroxenes and amphiboles were affected during the first and second stages of weathering, produced gibbsite, kaolinite and iron minerals. Formation of gibbsite and/or kaolinite is a function of the drainage intensity and nature of the solution. Magnetite and garnet altered at a later stage of weathering. A remarkable stability of quartz is observed in the bauxite profile, even in the last and mature stage of weathering. It altered only up to a limited extent, the size of the grains reduces due to breakage of subgrain boundaries and fractures. Its relict grains are thus found distributed throughout the profile. Garnet and magnetite have also been altered into iron minerals. Feldspar and pyroxene followed the similar trend of alteration and neo-mineralization results in the isomorphous replacement between Al and Fe minerals. Following five stages were noticed in the process of lateritization/bauxitization.

1. Desilicification of parent rocks by the weathering of primary silicate.
2. Formation of clay minerals (kaolinite).
3. Formation of Al/Fe oxides (gibbsite, goethite, limonite, etc.) and distribution of clays.
4. Migration of Fe or Al under the influence of Eh-pH and organic activities.
5. Oxidation of iron minerals and resilicification.

Petrochemical studies revealed the enrichment of Al_2O_3, Fe_2O_3 and TiO_2 with the depletion in SiO_2 content from charnockite through lithomargic clays to bauxites.

On the average the Al_2O_3 content in various zones varies from 29.45% in the zone of lithomargic clay, 50.77% in the bauxite zone to 20.46% in the lateritic zone as compared to 15.90% of Al_2O_3 in the parent rocks. Likewise, the concentration of Fe_2O_3 fluctuates from 22.15% in the lithomargic clay to 51.94% in the upper-most lateritic zone as compared to 4.62% in the charnockites. SiO_2 content on the other, depleted very much from 64.0% in the associated rocks to 6.71% in bauxites and 13.31% in laterites. LOI on the other also vary reveal an addition of water molecules from 15.50% in the lithomargic clays to 28.04% in the bauxites. It increases proportionately with the increase in alumina content in these samples. A few samples from the top-most lateritic zone revealed an appreciable content of P_2O_5 which reaches to 28.07% in some samples (Table-VI). This higher concentration of P_2O_5 in these laterites may be either due to resistant nature of apatite, organic activities and high ionic exchange efficiency for phosphate uptake in the laterites resulting in the formation of the new find 'Variscite-ferrian', an aluminium-iron phosphate, or to the action of phosphatic meteoric water on the pre-deposited laterites.

In the bauxite profile, concentration of alkalies and alkaline earths is negligible or occur only in traces as compared to the associated parent rocks.

The study of chemical data reveal sympathetic relationship between Al_2O_3 and TiO_2 whereas Fe_2O_3 and SiO_2 maintains negative or inverse relationship with Al_2O_3 (Figs. 16, 17, 20 & 22). Only in the upper-most zone of the profile P_2O_5 follows similar enrichment trend with Fe_2O_3. Sympathetic and antipathetic relationship between these oxides is predominantly or largely controlled by their chemical affinity and similarity or dissimilarity in the physico-chemical environment at the time of deposition. Presence of titanium in the bauxites play an important role in the fixation of alumina content. In the study area, lesser concentration of titanium in the parent rocks as well as in the bauxites has reflected in the poor quality of these bauxites.

The progressive and gradual enrichment of Al_2O_3 and Fe_2O_3 with the depletion of SiO_2 from the base to the lateritic zone (Table-VI) proved the residual origin of these bauxites.

The relative enrichment or depletion of the elements have been worked out by assuming the basement

rock having the original composition (Table-XII). It has been observed that most of the trace elements were leached out during the formation of bauxite. Only Ga, V, Zr and Cr revealed the trend of enrichment whose degree of enrichment is even more than that of aluminium, particularly in the lithomargic clay zone and in the zone of laterite of the profile. Copper enriched only in the zone of lithomargic clay, possibly due to its adsorbent property or high ionic exchange capacity (Table-XII). Concentration of gallium ranges from 10 to 30 ppm, vanadium and zirconium values reached up to 700 ppm and 1500 ppm respectively. While chromium averages in between 200-250 ppm (Table-X).

A slight enrichment of Cu, Pb, Zn, etc. was also observed in a few samples of the clay horizon.

The analytical results revealed that these bauxites contain lesser amount of trace elements as compared to the other Indian bauxites, because of poor concentration of these trace elements in the source rocks.

Correlation between the various elements revealed that Ga, Cr and Zr show a sympathetic relation with Al_2O_3 and TiO_2 (Figs. 34, 35 & 36; Table-XII) while V follows the trend of Fe_2O_3 (Fig. 40). Pb, Zn, La, Mn, Co, Ba, Sr and Ni on the other reveal a depleting trend upwards. Few

elements, viz., Sn, In, Ge, etc., did not show either depletion or concentration, because of their very meagre concentration.

Concentration or depletion of Al_2O_3, TiO_2, Fe_2O_3, SiO_2, etc., their association with each other and relationship between major and minor elements, are largely governed by the changes in physico-chemical conditions. The changes in the physico-chemical conditions of the solution acting on the rocks in contact, depends upon a number of factors such as nature of the rocks in contact, influence of vegetation, temperature, Eh-pH of the residuum, presence of other mineral substances and drainage conditions. In mafic rocks, pH will be more alkaline, while it will be neutral to acidic in the intermediate and garnetiferous rocks because of their leached constituents in that solution. Gibbsite, a chief aluminium mineral ($Al_2O_3.3H_2O$) was formed under alkaline conditions and at the same time increasing alkalinity would increase the mobility of SiO_2. Growth of vegetation and presence of organic acids, affects the pH of solution and therefore leads to relative enrichment of SiO_2 and TiO_2 in the reworked zone which would facilitate the migration of Fe and Al. pH of the ground water above 4 and a low Eh would be favourable in the formation of alumina rich horizon, besides activising the transport of iron.

To classify the bauxite deposits in general and Shevaroy hill bauxites in particular, a number of factors were considered viz., chemical composition, origin and mode of occurrence, mineralogical variations, textural features and geological age of the deposit. The classification based on the chemical composition and extent of lateritization have been proved quite satisfactory in the present study, because all other factors are also dependent on them. The terms laterite, aluminous laterite, bauxite, ferruginous bauxites, etc. are used for various rock units in the Shevaroy bauxite profile according to their chemical constituents. These bauxite deposits are classed as high level or upland deposits, which were formed by the residual weathering above the ground water table. Texturally, they may be termed as skeletal bauxites, in which relict textures of the parent rocks have been retained. Based on the correlatable planation surfaces and presence of trihydrate aluminous mineral, this deposit could be assigned Pre-Mio-Pliocene (Eocene) age.

In comparison of other bauxite deposits, the Shevaroy bauxite deposit is characterised by the following features :-

1. Derivation of this bauxite from the charnockite parentage.

2. Absence of typical and characteristic pisolitic and oolitic textures.
3. High SiO_2 and low Al_2O_3 content.
4. High Fe_2O_3 content and therefore lateritic in nature.
5. More free silica content.
6. Less concentration of trace elements.
7. Texture of parent rocks, showing alternate banding of dark and light coloured minerals.
8. Its occurrence, exceptionally, on high level landforms.

Finally, it may be concluded that Shevaroy bauxite deposits are the result of selective and preferential leaching of the underlying charnockites under variable physico-chemical environment. Quality, thickness and texture of the bauxite deposit is very much affected by the textural attributes of the parent rocks (non-porous and impervious), geomorphological and physiographical features of the terrain. Due to which the weathering could not reach to its maturity, whereby iron and silica were not removed to the required extent, that resulted in the lateritic and siliceous nature of these bauxites.

REFERENCES

REFERENCES

Adams, J.A.S. & Richardson, K.A. 1960 Thorium, Uranium and Zirconium Concentrations in Bauxite. Eco. Geol., 55, 1653-1675.

Ahmad, A. 1979 Geochemical relationship between the major oxides and their significance in the genesis of bauxite deposits of Phutka Pahar area, Bilaspur distt. M.P. M.Phil dissert., A.M.U.,Aligarh (Unpublished).

Alyengar, N.K.N. 1964 Minerals of Madras, Deptl of Indust. & Comm., 15-17.

Allen, V.T. 1948 Formation of bauxite from basaltic rocks of Oregaon. Eco. Geol., 43, 619-626.

_____ 1952 Petrographic relations in some typical bauxite and diaspore deposits. Bull. Geol. Soc. Am., 63(7) : 649-688.

_____ 1962 Permeability and lateral circulation in bauxite genesis, special paper, No. 73 of Geol. Soc. Am. 1973, 103 p.

Aleva, G.J.J.	1980	Bauxites and other duricrust on the Guinea shield, S. Africa. Proc. Intl. Sem. Later. Processes. Oxford Press, 261-269.
Aubert, G.	1965	Classification des sols Tebleaux des Classes, Sons-Classes, groups, et. Sons-groupes de sols utilises parla section de 'Pedologic de I' ORSTOM. ORSTOM Cahiers pedol., 3, 269-288.
Balasubramaniam, M.N.	1975	Significance of K-Ar age of biotite from charnockite type area, Madras. Geol. Surv. India. Misc. Pub., v. 23, pt. 1, 233-235.
Balasubramaniam, K.S.	1978	Mineralogy, Geochemistry and Genesis of bauxites of certain profiles from Western India, 4th Int. Cong. for the study of bauxites, alumina and aluminium, Athens, 1, Bauxites, 35-76.
Banerjee, P.K.	1972	Geology and Geochemistry of the Sukinda ultramafic field, Cuttack, distt., Orissa, Mem. Geol. Surv. Ind., 103.
_____	1975	A recconnaissance survey of the distribution of some trace elements in Indian bauxites. Miner. Deposita (Berlin), 10, 177-188.

Bardossy, Gy.	1963	Die Entwicklungder Bauxitgeologie Seit 1950. Sym. Bauxites, Zagreb, 1963, 1 : 31-50.
_____	1966	Bibliographic des Travaux Concer. nant les Bauxites publics en francais, angais, russe et allemand. ICOBA, Paris, 51 pp.
_____	1973	Bauxite formation and plate tectonics.Acta Geologica Academiae Scientiarum Hugaricae, Tomus, 17 (1-3).
_____	1979	*Role of Tectonism in the* formation of Bauxite deposits, Travaux de ICSOBA, Zagreb, no. 15.
_____	1980	Palaeo-environment of Laterites and Lateritic bauxite - effect of global tectonism on bauxite formation. Proc. Int. Sem. Later. Processes, Trivandrum, 287-292.
Bardossy, Gy. & Panto Gy.	1973	Investigation in bauxites by electrone probe, 3rd Int. Cong. for study of bauxites, alumina & aluminium, Nice, 47-55.

Bates, T.F.	1952	Interrelationship of structures and genesis in the Kaolinite group. Problem of clay and laterite genim, Amer. Inst. Min. Met., 144-153.
Beckwith, R.S. & Reeve, R.	1969	Dissolution and deposition of mono-silicic acid in suspension of ground quartz. Geochim. et Cosmochim. Acta, 23, 745-750.
Berthier, P.	1821	Analyse de Palumine hydratec des Baux. Ann. Mines, 6, 531-534.
Blatt, H.	1967	Original characteristics of clastic quartz grains. J. Sed. Petrol., 37, 401-424.
Blatt, H. & Christie, J.M.	1963	Undulatory extinction in quartz of igneous and metamorphic rocks and its significance in provenance studies of sed. rocks. J. Sed. Petrol., 33, 559-576.
Blanford, W.T.	1867	Section 15, country between the Nerbudda and Taptee bordering on the sea. Mem. Geol. Surv. Ind., 6, 194-210.
Boyle, R.W.	1974	Elemental association in mineral deposits and indicator elements of interest in geochemical prospecting (Revised). Energy, Mines & Resources, Canada, 40 p.

Britton, H.T.S.	1955	Hydrogen ions (4th edn.) Chapmen and Hall, London.
Buddington, A.F.	1933	Correlation of kinds of igneous rocks with kind of mineralization. Ore deposits of the western states, AIMME Lindgren, 350-385.
Burger, M.J.	1964	The precision method in X-ray Crystallograph. John Wiley & Sons, New York.
Butler, J.R.	1953	The Geochemistry and mineralogy of rock weathering, 1 : The Lizard area, Cornwall, Geochim, et Cosmochim Acta, 4, 157-178.
Campbell, J.M.	1917	Origin of laterite. Inst. Min. Met. Trans, 19, 432-443.
Chowdhury, A.N., Chakraberty, S.C., & Bose, B.B.	1965	Geochemistry of gallium in bauxite from India. Eco. Geol., 60, 1057 p.
Clayton, K.M.	1969	Weathering, Oliver, Boyd Edinburgh, 216-217.
Correns, C.W.	1963	Experiments on the decomposition of silicates and discussion of chemical weathering. Clays clay Mineral Symp. Pub., 1963, 443-459.
Correns, C.W. &	1938	Neue Untersuchungen Uber die Verwitterung des Kalifeldspates. Chem. Erde, 12, 1-22.

Deer, W.A., Howie, R.A. & Zussaman, J.	1962	Rock forming minerals, vol. 4, Longmans, London.
_____	1963	Rock forming minerals, vol. 5, Non-silicate, Longmans, London, 323-335.
De Weiss, J.G.	1948	Les bauxites de I'Europe - Centrale. Mem. Soc. Vaudoise Sci. Nat., 58(9), 1-162.
Fermor, L.L.	1911	Whate is Laterite? Geol. Mag. VIII, 454-462, 507-515, 559-566.
Fox, C.S.	1932	Bauxite and aluminous laterite, Crosby Lockwood & Son.
_____	1936	Buchanan's Laterite of Malabar and Kanara. Rec. Surv. India, XLIX, 389-422.
Fortescue, J.A.C.	1979	Environmental Geochemistry, Springer-Verlag, New York, Heidelberg Berlin, 330 p.
Frederickson, A.F.	1952	Regenetic significance of mineralogy Amer. Inst. Met. Eng., Problems of clay and laterite genesis, 1-11.
Frakes, L.A. & Kemp, E.M.	1972	Influence of continental position on early tertiary climates. Nature, 240, 5376, 97-100.

Ganapati, R. 1983 Non-ferrous metals in India - perspective of growth. Jour. of Mines Metals & Fuels, Jan., 1983, XXXI, 1, 3-9.

Gardner, L.R. 1972 Conditions for direct formation of gibbsite from K-feldspar - further discussion, Amer. Miner., 57, 294-300.

Goldschmidt, V.M. 1929 Ibid, B 2, 244.

_____ 1937 The principles of distribution of chemical elements in minerals and rocks. J. Chem. Soc. 655-673.

_____ 1954 Geochemistry, Clarendon, Oxford, 730 p.

Gilkes, R.J. 1973 The alteration products of K-depleted Oxy-biotite, Clays Clay Miner., 21, 3003-3013.

Gilkes, R.J. & Suddhiprakaran, A. 1980 Mineralogical and chemical aspect of Lateritization in southwestern Australia. Proc. Int. Sem. on Later. Processes, Trivendrum, 34-44.

Goldich, S.S. 1938 A study of rock weathering, Jour. Geol., 46, 17-58.

_____ " 1948 Origin and development of aluminous laterites and bauxites. Geol. Soc. Amer. Bull., 59, 1326 p.

Gopal Rao	1966	General report of the G.S.I. for the year 1962-63. Rec. of G.S.I., 97, I, 49-51.
Gopalkrishnan,K. Sugavanam,E.B. & Rao, V.V.	1975	Are there rocks older than dharwars? A reference to rocks in T.N., Indian Mineral., 16, 26-34.
Gordon, M. & Murata, K.J.	1952	Minor Elements in Arkausas bauxite, Econ. Geol., 47, 169-179.
Graham, E.R. & Baker, W.L.	1951	Ionic saturation of plant roots with special reference to hydrogen, Soil, Sci., 72, 435-451.
Green, J. & Poldervaart, A.	1958	Petrochemical fields and trends. Geochim. et Cosmochim. Acta., 13, 173-179.
Grubb, P.L.C.	1963	Critical factors in the genesis, extent and grade of some residual bauxite deposits. Econ. Geol., 58, 1267-1277.
_____	1969	Phase change in aged sesquioxides gels and some analogies with Katamorphic process. Miner. Deposita, 4, 30-51.
Hallsworth,E.C. & Costin, G.	1953	Origin of Laterites. J. Soil, Sci., 4, 24-46.
Haung, W.H. & Keller, W.D.	1971	Dissolution of rock-forming silicates in organic acids : simulated first stage weathering of fresh mineral surfaces. Am. Min., 55, 20-76-2094.

Hawkes, H.E. & Webb, J.S.	1962	Applied Geochemistry by Frederic. R. Siegel. A Wiley Int. Sci. Pub.
_____	1965	Geochemistry in mineral exploration. Harper & Row, New York, 416 p.
Heydemann, A.	1966	Uber die chemische verwitterung von Tonmineralen (experimentelle untersuchungen). Geochim. Cosmochim. Acta, 30(10), 995-1035.
Holland, T.H.	1900	The Charnockite Series. Mem. G.S.I. 28(2).
Hotz, P.E.	1964	Nickeliferous laterites in southwestern Orgon and northwestern California. Econ. Geol., 59, 355-396.
Humbert, R.P.	1949	Origin of Laterite, Soil Sci., 65,281 p.
I.B.M.	1977	Monograph on bauxite : Minerals facts and problems, 5, Controller I.B.M., Nagpur, India, 418 p.
	1969	Indian Mineral Yearbook
Israili, S.H.	1977	An attempt on the classification, nomenclature and genesis of Indian bauxites/laterites. Proc. of the Sem. on Raw Material for glass, ceramic and Refractory Industries.

Israili, S.H.	1978	Origin and classification of Indian phosphorites. A Geochemical approach. Third Reg. Conf. Geol. Min. Res. of S.E. Asia, Bangkok, Thailand, 267-274.
Jagannatha Rao,J. & Krishnamurty,C.V.	1980	Some observations on the mineralogy and Geochemistry of Hazaridadar and Raktidadar plateaus, Amarkantak area, M.P. Proc. Int. Sem. on Later. Process, Trivendrum, 89-108.
JCPDS	1975	Joint commission for Powder diffraction standard cards, New York.
Jenny, H.	1950	Origin of soils. Applied Sedim. (Ed. by P.D. Trask) Wiley, New York.
Jenny, H. & Overstreet, R.	1939	Cation Interchange between plant roots and soil colloids. Soil Sci., 47, 257-272.
Kalsotra, M.R. & Prasad, S.	1981	Geochemistry of trace elements in the laterites over Vindhyans. Indian Miner., 35, 1, 24-30.
Katsura, T., Kushiro, I., Akimoto,S.J., Walker, J.L. & Sherman, G.D.	1962	Titanomagnetite and titanomaghemite in a Hawaiian Soil. J. Sediment. Petr., 32, 299-308.
Keller, W.D.	1958	Argillation and direct Bauxitization in terms of concentration of hydrogen and metals cations at surface of hydrolysing silicates, A.A.P.G. Bull., 42, 233-245.

Keller, W.D. & Frederickson, A.F. 1952 Role of plants and colloidal acids in mechanism of weathering. Amer. Jour. Sci., 250, 594-608.

Kellog, C.E. 1949 Preliminary suggestions for the classification and nomenclature of great soil groups in tropical and equatorial regions. Comm. Bur. Soil Sci., Tech. Commun., 46, 76-85.

Khalighi, M. 1968 Zur untersuchung der Spurenelemente in den indischen Bauxiten, Lateriten und deren Ausgangsgesteinen Basalt und charnockit. Dipl. Arbeit, Hamburg, 76 p. (Unpublished).

Konta, J. 1958 Proposed classification and terminology of rocks in the series bauxite-clay-iron ore. J. Sed. Petrol., 28, 83-86.

Krauskopf, K.B. 1956 Dissolution and precipitation of silica at low temperatures. Geochim. Cosmochim. Acta, 10, 1-26.

Krishnan, M.S. 1942 Bauxite in the Shevaroy-Hills, Salem distt., Madras residency. Records Geol. Surv. India, 77, 1-16.

_____ 1953 The structural and tectonic history of India, Mem. G.S.I., 81.

_____ 1968 Geology of India and Burma, Higginbotham (P) Ltd., 387-388.

Krishna Rao,G. Borreswara Rao,C. & Shyam Sunder,Y. 1974 Mineralogical studies on the bauxites from Shevaroy hills, T.N., J. Geol. Soc. India, 15, 58-64.

Krishna Rao, G. & Borreswara Rao,C. 1976 Decomposition of primary minerals and the process of bauxitization in Shevaroy and Kolli Hlls, Salem distt., T.N. J. Geol. Soc. India, 17, 530-538.

Krishnaswamy, S. 1958 Bauxite occurrences in the Shevaroy Hills, Salem distt., G.S.I. (Unpub.)

Kronberg, B.I., Fyfe, W.S., Mc Kinnon, B.J., Couston, J.F., Stillianidi Filhi,B. & Nash, R.A. 1982 Model for bauxite formation. Chem. Geol., 35 (3/4), 297-310.

Lacroix, A. 1913 Les laterites de la Guinee et les produits d'alteration quileur Sont associes. Nouv. Arch. Mus., 5, 255-258, Paris.

Landgren, S. 1943 Geokemiska studies over Grangesfalters Jarnmalmer Ing. Vetenskaps Akad. Handl. No. 172.

Laughnan, F.C. 1962 Some considerations in the weathering of the silicate minerals. Jour. Sed. Pet., 32, 2.

Loughman, F.C. & Bayliss, P. 1961 The mineralogy of bauxite deposits near Weipa, Queensland. Am. Mineralogist, 46, 209-217.

Levinson, A.A. 1979 Introduction to exploration geochemistry. Appl. Pub. Ltd. Wilmette, Illinois, U.S.A.

Marbut, C.F. 1932 Proc. 2nd Int. Cong. Soil Sci. 5, 72-80.

Mason, B. 1966 Principles of geochemistry, Wiley, New York, 329 p.

Mc Farlane, M.J. 1968 Laterite and landscape. Acad. Press, London, New York, San Francisco.

_____ 1976 Laterite and landscape, Academic Press, London, 31-32.

_____ 1980 Morphological mapping in laterite areas and its relevance to the location of economic minerals in laterites. Proc. Int. Sem. Later. Process, 307-317.

Mc Laughlin, R.J.W. 1959 The geochemistry of some kaolinitic clays, Geochimet Cosmochim Acta, 17, 11-16.

Mead, W.J. 1915 Occurrence and origin of the bauxite deposits of Arkansas. Econ. Geol., 10, 28-54.

Migdisow, A.A. 1960 On the titanium-aluminium ratio in sedimentary rocks. Geochemistry, 2, 178-194.

Moss, J.H. & Michell, W.D.	1963	Bauxite deposits of British Guiana and Surinam in relation to underlying unconsolidated sediments suggesting two-step origin. Econ. Geol., 58, 250-262.
Nair, A.M. & Mathai, T.	1980	Geochemical trends in some laterite profiles of North Kerala. Proc. Int. Sem. on Later. Process, Trivendrum, 114-119.
Narayanaswamy,S.	1971	Proposal for charnockite-khondalite system in the Archean Shield of Peninsular India. Sem. on Pre-Camb. Form. of Penin. Shield. Geol. Surv. India, Calcutta, Oct., 1971 (Abstract).
_____	1974-75	Charnockite-Khondalite and Sargur-Nellore-Khammam-Bengpal-Deogarh-Pallahara-Mahagiri rock groups - Older than Dharwar type greenstone belt in the Peninsular Archean. Indian Mineralogist, 16, 16-25.
Norton, S.A.	1973	Laterite and bauxite formation, Econ. Geol., 68, 353-361.
Panicker,M.R.K. Chikkerur,B.S. Palani, S. Aswathanarayan,G.K. & Panduranga Rao,T.N.	1973	Studies on relationship between LOI and alumina content in bauxites. Ind. Mineral. 27(1).

Paterson,S.H. 1967 Bauxite reserves and potential aluminium resources of the world. U.S. Geol. Surv. Bull., 1228, 176 p.

Paterson, Ulrich 1971 Laterite and bauxite formation. Econ. Geol., 66, 1070-1071.

Paul, D.K. 1966 Role of permeability in the formation of bauxites. Indian Miner., 20, No. 3, 284-286.

_____ 1969 Titanium in bauxite. Indian Minerals Vol. 23,

Pedro, G. 1964 Contribution a l'etude experimentale de l'alteration geochimique des roches cristallin. Ann. Agron, 15(2, 3, 4), 344 p.

Pickering, R.J. 1962 Some leaching experiments on three quartz free silicate rocks and their contribution to the understanding of lateritization. Econ. Geol., 57, 1185-1206.

Pollack, H.R. 1980 Bauxites and laterites of the Bakhuis mountain zone, western Suriname, a general description with emphasis on geomorphology and chemistry. Proc. Int. Sem. Lat. Process, Trivendrum, 270-286.

Pollack, H.R. 1980 Genetic implication of major elements distribution of bauxites and laterites of Suriname. Proc. Int. Sem. on Later. Process, Trivendrum.

Prasad, K.K. & Ray, S.P.S. 1980 Role of ground water in the lateritization of hills around Gauhati, Assam. Proc. Int. Sem. on Later. Process, Trivendrum, 391-400.

Radhakrishnan, B.P. 1968 Geomorphological approach to Charnockite proble. Jour. Geol. Soc. India, 9, 67-74.

Rahman, A. 1978 The Geochemistry and Genesis of Lohardaga Bauxite Deposits, Ranchi Distt., Bihar, Ph.D. Thesis, A.M.U., Aligarh (Unpubl.).

Raman, P.K. 1976 The bauxite deposits of Anantgiri, Vishakhapatnam district, A.P.. Jour. Geol. Soc. of India, 17, No. 2, 236-244.

———— 1978 Bauxite residium derived from Khondalite and charnockite. Jour. Geol. Soc. of India, 9, No. 4, April, 1978.

Ramam, P.K. 1978a Genesis and geomorphic significance of the east coast bauxite deposits of India. 3rd Reg. Conf. on Geol. & Min. Res. of SE Asia, Bangkok, Thailand, 351-355.

_____ 1978b Genesis and geomorphic significance of the east coast bauxite deposits of India. Reg. Conf. on Geol. & Min. Res. of SE Asia (3rd), Bangkok, Thailand.

_____ 1981 Bauxite Resources in A.P. Jour. Geol. Soc. India.

_____ 1981 Geomorphic evolution and its significance in exploration planning of the east coast bauxite deposit of India. Jour. Geol. Soc. of India. 22, No. 10, 488-495.

Ramanujan,C.G.K. 1968 Some observations on the flora of the Cuddalore sandstones series, Cretaceous-Tertiary formations of South India. Geol. Soc. Ind. Mem. 2, 271-285.

Rankama, K. & Sahama, Th. G. 1949 Geochemistry, Chicago & Helisinki Press.

Ray Mahashay,B.C. Bhavana, P.R. & Mehta, V.K. 1984 Ion exchange properties of lateritic soil from Calicut, Kerala. Jour. Geol. Soc. of India, 25, No. 7, 466-470

Reich, F. 1950 A survey of weathering process and product. New Mexico University Pub. Geology No. 3.

Rose, C.S. 1943 Clay and soils in relation to geologic process. Jour. Wash. Acad. Sci., 33, 225-235.

Roy Chowdhury,R. 1958 Bauxite in Bihar, M.P., Vindhya Pradesh, Madhya Bharat and Bhopal. Mem. Geol. Surv. India, 85, 1-271.

Roy Chowdhury,M.K. & Anand Alwar,M.A. 1964 Loss on Ignition as a guide in prospecting for bauxite. Indian Minerals, 18, 49-54.

Sahasrabudhe,Y.S. 1978 Bauxite deposits of Gujarat, Maharasthra and parts of Karnatak. Bull. of Geol. Surv. India. Ser. A. Econ. Geol. No. 39.

_____ 1978 Geochemistry of bauxite profile on different rock types from central and western India, 4th Int. Cong. for the study of bauxite, alumina and aluminium. Athens, Vol. 2 Bauxites, 734-752.

Sahasrabudhe,Y.S. & Deshmukh, S.S. 1980 The laterites of the Maharashtra state. Proc. Int. Sem. Later. Process. Oxford Press, 209-220.

Sahoo, R.K. Kaaden, G.V.D. & Muller, G.	1980	The mineralogy and geochemistry of nickeliferous laterite of Sukinda, Orissa, India. Proc. Int. Sem. on Later. Process, Trivendrum, 77-85.
Sahni, A. & Kumar, V.	1974	Palaeogene palaeobiography of the Indian sub-continent. Jour. Palaeogeon., palaeoclimat., palaeoecology, 15, No. 3, 209-229.
Sapozhnikov,D.G.	1963	On the substraction of aluminium by organic acids from minerals and rocks in the course of weathering. Symp. Sauxites, Zagreb, 1963, 1 : 107-113.
Schellmann, W.	1980	Considerations on the definition and classification of laterites. Proc. Int. Sem. Later. Processes. Oxford Press, 1-10.
Seeliger, E.	1962	Paragenetische unter-suchungen an C-Erzen (Weicherzen) Von Konakry, Guinea, Fortschr. Mineral, 39, 139-141.
Selby, H.J.	1971	The surface of the Earth Cussel & Co. Ltd., 96-97.
Sevaraj Singham,S.	1962	Laterite. Advam. Agron, 14, 1-60.
Shapiro, J.	1964	Effects of yellow organic acids on iron and other metals in water. Am. Water Works Assoc. Jour., 56, 1062.

Shapiro, L. & Brannock, W.W.	1956	Rapid analysis of silicate rocks. U.S. Geol. Surv. Bull., 1036(C), 53-84.
Shaw, D.M.	1957	The Geochemistry of gallium, irradiu, thallium, a review. Phy. Chem. Earth, vol. 2.
Sherman, G.D.	1952	The Titanium content of Hawaian soils and its significance. Soil Sci.,Proc., 16, 15-18.
Sherman, G.D. & Uehara, G.	1956	The weathering of Olivine Basalt in Hawaii and its Pedogenic Significance. Soil Sci. Soc. Am. Proc., 20, 237-340.
Srinivasan, V.	1974	Geological structure in Attur valley, T.N., based on photo-interpretation. Jour. Geol. Soc. India, 15, 89-93.
Subramanian,A.P.	1959	Charnockites of the type area near Madras - a reinterpretation. Amer. Jour. Sci., 257, 321-353.
———	1960	Petrology of charnockite suite of rocks from the type area around St. Thomas Mount and Pallavaram, Near Madras, Int. Geol. Cong., 21st session, Nordon, Part XIII, 394-403.

Subramanian, K.S.	1978	How old are laterites in the Indian Peninsula? - a suggestion. Jour. Geol. Soc. of India, 19, no. 6.
Subramanian, K.S. & Mani, G.	1978	Implications of Laterites in high landforms in T.N. Symp. on Morph. and Evol. of Landforms. Dept. of Geol. Univ. of Delhi, Dec. 22-23, 1978.
_____	1978	Palaeo-climate and laterite formation in Tertiary - A case study in the southern part of the Indian Peninsula. Indian Minerals, vol. 32, No. 3.
_____	1979	Geomorphic significance of Laterite-bauxite in the Shevaroy and Kollaimalai hills, Salem distt., T.N. J. Geol. Soc. Ind., vol. 20, No. 6, 285-288.
_____	1980	Genetic and Geomorphic aspects of Laterites on high and low Landforms in parts of T.N. India. Proc. Int. Sem. on Later.Process, Trivendrum, 237-244.
Valeton, I.	1966	Sur la genese des gisements de bauxite du sud-est de la France. Bull. Soc. Geol. France, 7, 685-701.
_____	1972	Bauxites, Elsevier Publishing Company, New York.

Valeton, I. 1980 Bauxites on peneplained metamorphic and magmatic rocks on detrital sediments and on karst topography. Their similarities and contrst of genesis. Proc.Int. Sem. on Later. Processes, Oxford Press, 15-23.

Vadasz, E. 1951 Bauxitfoldtan. Akad. Kiado, Budapest, 129 p.

Vaidyanadhan, R. 1967 An outline of the Geomorphic of India South of North latitude 18°. Proc.Sem. on Geomorp. Stud. in India, Sagar, 129-137.

Vogt, J.H.L. 1918 Die Sulfid : Silikatschmelzloszungen I. Die sulfid-schmelzen und die sulfid : Silikatschmelzen videnskapsselskapets Skrifter I. Mat. naturv. klasse, No. 1.

Wagner, P.
Williams, J.M.
Wewerka,E.M.
Bertino, J.P.
Wanger, L.W. &
Wanek, P.L. 1980 Trace element contamination of drainage from coal cleaning wastes. Am. Inst. Chem. Eng., 21, 79-86.

Washington, H.S. 1913 The distribution of elements in igneous rocks: Ore Deposits. Am. Inst. Min. Met. Eng.

Wadepohl,K.H. 1970 Handbook of Geochemistry, vol. III.

Weefers, K. 1966 Zum System Fe_2O_3 - H_2O. Ber. Deut. Keram. Ges, 43, 677-684; 703-708.

West,G. & Dumbelton, J.J. 1970 The mineralogy of tropical weathering illustrated by some West Malaysian soils. Quart. Jour. Eng. Geol., 3(1), 25-40.

Wey, R. & Siefert, B. 1961 Reaction de la silice monomoleculaire en solution avec les ions Al^{3+} et Mg^{2+}. Genese et Synthese des argiles. Colloq. Int. Centre Nat. Rech. Sci (Paris), 105, 11-23.

Williams, D.E. & Coleman, N.T. 1950 Cation exchange properties, plant root surfaces, plant and soil, 2, 243-256.

Wolfenden, E.B. 1965 Geochemical behaviour of trace elements during bauxite formation in Sarawak Malaysia. Geochim, Cosmochim Acta, 29, 1051-1062.

Wollast, R. 1963 Aspect chimique due monde de formation des bauxites dansle Bascongo. Confrontation des donnees thermodynamiques et experimentales. Acad. Roy. Sci. Ontre-Mer, Bull. Belg.; Ser. 7, 2, 392-412.

Zans, V.A. 1959 Recent views on the origin of Bauxite. Geonotes, 1(5), 123-132.

Zeissink, H.E. 1969 The mineralogy and geochemistry of a nicke-laterite profile. Mineral. Deposita. 4, 132-152.

Zubovic, J.E. 1961 The association of minor element associations in coal and other carbonaceous sediments. U.S. Geol. Surv. Prof. Pap., 424-D, D345-D348.

Zussaman, J. 1970 & 1977 X-ray diffraction in physical methods in determining mineralogy edited by Zussaman. Acad. Press, London.

TABLES

TABLE VI :- REPRESENTS DISTRIBUTION OF MAJOR OXIDES IN VARIOUS ZONES OF SHEVAREY BAUXITE DEPOSITS (YERCAUD) AND ASSOCIATED PARENT ROCKS (IN TERMS OF PERCENTAGE).

S.NO	SAMPLE NO	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	H_2O	TOTAL	Al_2O_3/Fe_2O_3
1	1/4	59.60	4.19	2.78	0.57	0.05	<25*	0.08	0.20	0.01	32.53	100.01	14.22
2	1/7	56.82	6.16	6.18	0.48	0.28	<25*	50*	0.04	Tr	30.18	100.14	9.22
3	1/10	56.92	8.35	1.78	0.50	0.28	<25*	25*	0.09	Tr	31.60	99.70	6.67
4	1/13	40.39	32.50	0.56	1.39	0.14	<25*	0.05	0.04	0.01	24.89	99.97	1.24
5	1/14	58.93	5.96	1.30	0.29	0.07	<25*	25*	0.03	Tr	32.79	99.37	9.88
6	2/5	39.21	30.39	4.93	1.06	0.27	<25*	0.08	Tr	Tr	23.19	99.13	1.29
7	2/6	49.00	11.29	11.56	1.56	0.08	50*	0.02	0.06	0.02	26.60	100.19	4.34
8	2/13	48.73	18.07	0.89	2.78	0.31	<25*	25*	0.04	Tr	29.03	99.85	2.69
9	3/2	55.38	6.86	6.84	0.39	0.31	50*	0.01	0.03	Tr	29.30	99.12	8.07
10	3/3	34.39	27.70	16.24	0.86	0.20	<25*	75*	0.03	0.01	20.17	99.60	1.24
11	3/4	53.91	3.35	12.31	0.53	Tr	<25*	25*	0.04	Tr	29.40	99.54	16.09
12	3/5	42.89	7.35	27.64	0.94	0.06	<25*	0.01	0.03	Tr	20.77	99.51	5.83
13	3/8	55.30	1.60	13.14	0.29	0.06	<25*	25*	0.03	Tr	29.27	99.69	34.56

contd.....

S.NO.	SAMP.NO.	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	H_2O	TOTAL	Al_2O_3/Fe_2O_3
14	3/9	55.53	8.76	3.69	1.96	0.09	50*	0.03	0.01	Tr	30.12	100.19	6.33
15	4/1	52.60	2.20	15.84	0.60	0.05	<25*	0.08	0.41	Tr	28.24	100.02	23.90
16	4/3	58.20	8.18	0.54	0.40	0.11	<25*	50*	0.01	Tr	32.64	100.08	7.11
17	4/7	35.30	36.90	0.57	4.60	0.54	<25*	0.07	0.03	0.02	21.31	99.34	0.95
18	4/9	47.70	21.96	0.90	1.50	0.05	<25*	0.01	0.01	Tr	27.39	99.52	2.17
19	4/16	48.78	19.80	6.18	1.02	0.08	<25*	50*	0.04	Tr	-	100.87	2.46
20	5/2	53.00	3.95	14.14	0.60	0.08	<25*	75*	0.03	Tr	28.04	99.84	13.41
21	5/3	48.53	13.52	10.27	0.78	0.17	<25*	50*	0.03	Tr	26.17	99.47	3.58
22	6/1	59.10	3.53	4.30	0.30	0.06	<25*	25*	0.01	Tr	32.44	99.74	16.74
23	6/3	57.19	8.99	0.18	1.79	0.21	<25*	25*	0.02	Tr	31.45	99.77	6.35
24	6/5	54.35	11.70	0.68	1.43	0.25	<25*	25*	0.03	Tr	31.47	99.61	4.64
25	1/3	29.99	50.42	6.18	0.27	0.29	<25*	25*	0.04	0.04	12.28	99.51	0.59
26	1/5	12.02	55.26	21.64	3.59	0.23	50*	50*	0.06	0.07	8.11	100.98	0.21
27	1/18	15.56	54.59	6.86	0.49	0.18	25*	50*	0.06	0.06	11.44	99.24	0.28
28	2/2	31.36	40-11	5.96	0.99	0.74	75*	<25*	0.03	0.02	20.51	99.72	0.78
29	2/7	19.87	48.31	12.10	2.50	0.13	50*	25*	0.05	0.04	16.28	99.23	0.41
30	2/11	13.42	71.72	5.36	0.31	0.25	50*	25*	0.05	0.06	9.16	99.93	0.18

contd.....

S.No.	Sam.No.	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	H_2O	TOTAL	Al_2O_3/Fe_2O_3
31	3/1	10.90	57.60	22.85	0.62	0.30	50*	0.01	0.04	0.05	7.56	99.98	0.18
32	3/7	20.11	51.20	12.10	0.39	0.23	50*	<25*	0.02	Tr	16.15	100.20	0.39
33	3/10	16.29	66.11	5.20	0.42	0.22	50*	25*	0.04	0.04	11.24	99.56	0.24
34	4/2	13.99	53.76	19.68	0.31	0.26	<25*	50*	0.04	0.04	10.98	99.56	0.26
35	4/8	19.20	47.60	20.70	0.40	0.08	25*	0.01	0.04	0.04	11.54	99.61	0.40
36	4/10	32.86	44.92	3.94	0.72	0.39	25*	<25*	0.03	Tr	16.88	99.74	0.73
37	4/19	15.20	56.00	18.42	0.30	0.12	75*	50*	0.04	0.04	9.32	99.44	0.27
38	5/1	18.29	52.09	18.13	0.36	0.09	25*	50*	0.05	0.02	10.24	99.27	0.35
39	6/2	37.92	28.30	9.67	1.14	0.12	<25*	0.01	0.01	0.01	22.53	99.68	1.33
40	1/9	37.02	3.99	42.41	1.67	0.22	<25*	75*	0.04	Tr	14.33	99.49	9.27
41	1/12	30.17	21.95	32.89	0.94	0.20	25*	50*	0.02	Tr	13.27	99.83	1.37
42	2/1	37.92	4.79	20.47	0.28	0.16	<25*	0.01	Tr	Tr	16.40	100.03	7.91
43	2/16	27.17	28.11	24.44	1.03	0.11	<25*	50*	Tr	0.02	19.15	99.46	0.96
44	3/6	36.18	4.96	42.89	1.46	0.33	<25*	75*	Tr	0.01	13.63	99.95	7.29
45	3/12	40.83	19.47	15.86	1.23	0.26	<25*	50*	Tr	Tr	22.30	99.76	2.09
46	4/5	28.70	24.30	32.80	1.33	0.19	25*	50*	Tr	Tr	12.39	99.22	1.18
47	4/20	22.53	33.48	25.10	1.09	0.17	50*	<25*	Tr	Tr	16.85	99.96	0.67
48	5/5	20.53	33.31	29.63	1.26	0.13	<25*	50*	Tr	Tr	15.11	99.20	0.61

contd.....

S.No.	Sam.No.	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	H_2O	TOTAL	Al_2O_3/Fe_2O_3
49	6/4	13.52	47.15	25.12	1.18	0.23	50*	0.01	Tr	0.01	11.96	99.73	0.28
50	2/8	22.78	15.99	11.35	1.13	28.71	<25*	0.06	0.04	0.02	19.71	99.48	1.42
51	2/9	23.46	14.98	11.39	1.40	27.43	<25*	0.04	0.01	0.02	20.75	100.04	1.56
52	1/19	17.01	5.11	61.81	0.38	0.04	5.09	4.28	4.36	1.33	0.63	100.59	3.32
53	1/21	16.09	5.31	62.05	0.73	0.26	5.28	4.96	4.68	1.09	0.49	99.57	3.03
54	2/14	16.09	4.45	64.09	0.47	0.06	4.80	4.30	4.15	1.05	0.18	99.59	3.61
55	2/17	17.04	4.37	63.92	0.41	0.08	4.72	4.22	4.12	1.03	0.54	100.85	3.89
56	3/15	15.01	4.15	66.30	0.25	0.15	4.50	4.10	3.84	1.14	0.23	99.59	3.61
57	3/17	14.93	5.17	65.09	0.37	0.11	4.86	4.21	4.09	1.21	0.29	100.33	2.88
58	4/21	16.74	3.48	63.61	0.57	0.07	4.92	4.40	4.35	1.10	0.40	99.64	4.81
59	5/7	15.83	4.33	64.13	0.49	0.09	4.99	4.31	4.39	1.16	0.36	100.08	3.65
60	6/6	14.38	5.23	65.06	0.68	0.13	5.11	3.89	4.72	1.29	0.32	100.81	2.74

Sample Nos. 1-24 ---- Bauxites 40 - 49 Lithamargic clay

25 - 39 -- Laterites 50 - 51 Phosphatic Bauxite

52 - 60 Parent Rocks

* Represents values in ppm.

TABLE VII :- REPRESENTS RECALCULATED VALUES OF SiO_2, Fe_2O_3 AND Al_2O_3 IN PERCENTAGE

Sample No	SiO_2	Fe_2O_3	Al_2O_3
1	4.17	6.29	89.51
2	8.93	8.90	82.10
3	2.64	12.68	84.64
4	0.76	44.23	54.97
5	1.96	8.99	88.98
6	6.61	40.75	52.58
7	16.08	15.70	68.15
8	1.31	26.68	71.97
9	9.90	9.92	80.13
10	20.73	35.34	43.88
11	17.69	4.81	77.46
12	35.34	9.45	55.19
13	18.76	2.28	78.91
14	5.40	12.87	81.86
15	22.42	3.11	74.42
16	0.80	12.22	86.95
17	0.78	50.70	48.50
18	1.27	31.11	67.59
19	8.28	26.56	65.22
20	19.89	5.55	74.51

contd.....

Sample No.	SiO_2	Fe_2O_3	Al_2O_3
21	14.20	18.68	67.06
22	6.42	5.27	88.29
23	0.27	13.53	86.15
24	1.01	17.52	81.41
25	7.13	58.18	34.60
26	24.35	62.02	13.50
27	19.37	62.72	17.87
28	7.69	51.78	40.48
29	15.07	60.14	24.73
30	5.96	79.08	14.92
31	24.99	63.06	11.92
32	14.50	61.33	24.09
33	5.93	75.43	18.58
34	22.58	61.44	15.92
35	23.65	54.35	21.92
36	4.82	54.93	40.18
37	20.55	62.44	16.94
38	20.48	58.80	20.64
39	12.74	37.27	49.94
40	50.83	4.78	44.37
41	38.68	25.81	35.48
42	48.52	5.77	45.69
43	30.64	35.24	34.07
44	51.04	5.90	43.05
45	20.82	25.56	53.60

contd.....

Sample No.	SiO_2	Fe_2O_3	Al_2O_3
46	38.22	28.30	33.43
47	30.94	41.24	27.75
48	35.50	39.90	24.58
49	29.28	54.92	15.75
50	22.67	31.82	45.21
51	22.57	30.10	47.01
52	73.64	6.08	20.25
53	74.35	6.36	19.27
54	75.72	5.25	19.00
55	74.90	5.11	19.95
56	77.58	4.85	17.56
57	76.40	6.06	17.51
58	75.77	4.28	19.93
59	76.08	5.13	18.77
60	76.83	6.17	16.98

TABLE VIII :- REPRESENTS RECALCULATED VALUES OF SiO_2, Fe_2O_3 AND $Al_2O_3 + TiO_2$ IN PERCENTAGE

S.NO.	SiO_2	Fe_2O_3	$Al_2O_3 + TiO_2$
1	4.14	6.23	89.57
2	8.83	8.80	82.28
3	2.81	12.53	84.40
4	0.74	43.42	55.82
5	1.95	8.96	89.07
6	6.51	40.17	53.27
7	15.74	15.37	68.87
8	1.26	25.64	73.09
9	9.84	9.87	80.27
10	20.49	34.95	44.51
11	17.55	4.77	77.63
12	34.90	9.34	55.73
13	18.67	2.27	79.03
14	5.30	12.57	82.18
15	22.22	3.08	74.61
16	0.80	12.14	87.04
17	0.73	47.67	51.57
18	1.24	30.45	68.27
19	8.16	26.11	65.68
20	18.71	5.50	74.76

contd.....

S.No.	SiO_2	Fe_2O_3	$Al_2O_3+TiO_2$
21	14.03	18.48	67.45
22	6.39	5.24	88.35
23	0.26	13.19	86.53
24	0.99	17.16	76.90
25	7.11	58.02	34.83
26	16.87	59.68	16.86
27	19.26	62.34	18.33
28	7.60	51.14	41.24
29	14.61	57.97	26.84
30	5.94	78.83	15.21
31	24.81	62.60	12.51
32	14.44	61.18	24.45
33	5.90	75.10	18.98
34	22.50	61.34	16.22
35	23.55	54.12	22.28
36	4.78	54.48	40.73
37	20.71	63.04	17.42
38	20.40	58.60	20.98
39	12.55	36.73	50.69
40	49.83	4.68	45.46
41	38.21	25.50	36.23
42	48.36	5.75	45.88
43	30.25	34.80	34.92
44	50.13	5.79	44.02
45	20.49	25.15	54.34

contd.....

S.No.	SiO_2	Fe_2O_3	$Al_2O_3+TiO_2$
46	37.62	27.87	34.50
47	30.52	40.71	28.74
48	34.96	39.30	25.70
49	28.86	54.17	16.90
50	22.17	31.18	46.50
51	22.21	29.21	48.52
52	73.30	6.06	20.61
53	76.07	6.30	19.98
54	75.30	5.22	19.45
55	74.53	5.09	20.35
56	77.30	4.83	17.80
57	76.02	6.03	17.88
58	75.31	4.12	20.49
59	75.60	5.10	19.24
60	76.18	6.12	17.64

Table IX :- REPRESENTS MAJOR ELEMENTS DISTRIBUTION IN VARIOUS ZONES OF BAUXITE PROFILE AND ASSOCIATED PARENT ROCKS IN THEIR ELEMENTAL FORM.

Sample No.	Al	Fe	Si	Ti
1	31.55	2.93	1.27	0.34
2.	30.08	4.31	2.84	0.28
3	30.13	5.97	0.81	0.30
4	21.38	22.75	0.25	0.83
5	31.79	4.17	0.59	0.17
6	20.76	21.27	2.26	0.63
7	25.94	7.90	5.31	0.93
8	25.80	12.64	0.40	1.66
9	29.32	4.80	3.14	0.23
10	18.21	19.39	7.47	0.51
11	28.54	2.34	5.66	0.31
12	22.71	5.14	12.63	0.56
13	29.27	1.12	6.04	0.17
14.	28.87	6.13	1.69	1.17
15	27.85	1.54	7.28	0.36
16	30.81	5.72	0.24	0.24
17	18.69	25.83	0.26	2.76
18.	25.25	15.37	0.41	0.90
19	24.77	13.90	2.84	0.61
20	28.06	2.76	6.50	0.36
21	25.69	9.46	4.72	0.46

Sample No.	Al	Fe	Si	Ti
22	31.29	2.47	1.97	0.18
23	30.24	6.29	0.08	1.07
24	28.77	8.19	0.31	0.85
25	15.87	35.29	2.84	0.16
26	6.47	39.87	9.95	0.35
27	8.23	38.21	3.15	0.29
28	16.60	28.07	2.74	0.59
29	10.52	33.81	5.56	1.50
30	7.10	49.78	2.46	0.18
31	5.77	40.35	10.51	0.37
32	10.64	35.84	5.56	0.23
33	8.62	46.27	2.39	0.25
34	7.26	37.63	9.05	0.18
35	10.16	33.32	9.52	0.24
36	17.39	31.44	1.81	0.43
37	8.04	39.20	8.47	0.18
38	9.68	36.46	8.33	0.21
39	20.07	19.81	4.40	0.68
40	19.60	2.79	19.50	1.00
41	15.97	15.36	15.11	0.59
42	20.07	3.35	18.52	0.16
43	14.38	19.67	11.24	0.61
44	19.15	3.47	19.72	0.87
45	21.61	13.62	7.29	0.73
46	15.19	17.01	15.08	0.82

contd.....

Sample No.	Al	Fe	Si	Ti
47	11.93	23.43	11.54	0.65
48	10.86	23.31	13.62	0.75
49	7.16	33.00	11.55	0.70
50	11.81	0.79	5.22	0.67
51	12.16	10.48	5.23	0.84
52	8.84	3.57	28.43	0.22
53	8.36	3.71	28.54	0.43
54	8.36	3.11	29.48	0.28
55	8.86	3.05	29.40	0.24
56	7.80	2.90	30.49	0.15
57	7.76	3.61	29.94	0.22
58	8.70	2.43	29.26	0.34
59	8.23	3.03	29.49	0.29
60	7.47	3.66	29.92	0.40

TABLE X :- REPRESENTS THE CONCENTRATION OF TRACE-METALS IN VARIOUS ZONES OF SHEVAROY BAUXITES DEPOSITS (YERCAUD) AND ASSOCIATED PARENT ROCKS.(IN TERMS OF ppm).

S.NO	SAMPLE NO	Li	Mn	Cu	Pb	Zn	Ni	Co	Ba	Sr	Sn	Mo	Cr	In	Ge	Be	Zr	V	Y	Ga
1	1/4	<5	<10	7	<10	<25	<10	<10	<50	<100	<20	<5	400	<10	<10	<5	<20	170	<20	15
2	1/7	<5	10	5	<10	<25	<10	<10	<50	<100	<20	<5	400	<10	<10	<5	50	150	<20	<5
3	1/10	<5	10	5	<10	<25	<10	<10	<50	<100	<20	<5	100	<10	<10	<5	50	200	<20	15
4	1/13	<5	20	<5	10	25	20	<10	<50	<100	<20	5	500	<10	<10	<5	500	200	<20	15
5	1/14	<5	<10	10	<10	<25	<10	<10	<50	<100	<20	<5	1500	<10	<10	<5	300	150	<20	20
6	2/5	<5	200	20	10	25	<10	10	50	<100	<20	10	1200	<10	<10	<5	1000	150	<20	15
7	2/6	10	15	10	<10	<25	10	<10	<50	<100	<20	<5	1000	<10	<10	<5	150	150	30	10
8	2/13	<5	<10	<5	<10	25	60	<10	<50	<100	<20	5	1000	<10	<10	<5	700	700	20	30
9	3/2	<5	<10	10	<10	<25	20	<10	<50	<100	<20	<5	500	<10	<10	<5	100	50	<20	15
10	3/3	<5	15	<5	10	25	<10	<10	<50	<100	<20	10	500	<10	<10	<5	500	150	<20	10
11	3/4	<5	15	<5	20	<25	10	<10	<50	<100	<20	10	150	<10	<10	<5	70	50	<20	5
12	3/5	<5	<10	20	<10	25	100	<10	<50	<100	<20	<5	700	<10	<10	<5	700	150	<20	10
13	3/8	<5	<10	15	<10	<25	15	<10	<50	<100	<20	<5	100	<10	<10	<5	100	70	<20	5

S.No.	Samp.No.	Li	Mn	Cu	Pb	Zn	Ni	Co	Ba	Sr	Sn	Mo	Cr	In	Ge	Be	Zr	V	Y	Ga
14	3/9	<5	<10	5	<10	<25	50	<10	<50	<100	<20	<5	500	<10	<10	<5	150	500	<20	5
15	4/1	<5	15	5	10	25	<10	<10	<50	<100	<20	<5	100	<10	<10	<5	170	150	<20	7
16	4/3	<5	70	20	<10	25	<10	<10	<50	<100	<20	<5	300	<10	<10	<5	20	300	<20	15
17	4/7	<5	500	5	200	25	20	<10	150	<100	<20	<5	1500	<10	<10	<5	1000	150	<20	10
18	4/9	<5	15	<5	10	25	<10	<10	<50	<100	<20	<5	500	<10	<10	<5	700	100	<20	15
19	4/16	<5	10	7	10	<25	<10	<10	<50	<100	<20	<5	300	<10	<10	<5	500	150	<20	15
20	5/2	<5	<10	10	10	<25	40	<10	<50	<100	<20	<5	20	<10	<10	5	150	150	<20	10
21	5/3	10	60	<5	10	<25	30	<10	<50	<100	<20	<5	500	<10	<10	5	70	50	30	30
22	6/1	<5	<10	5	10	<25	<10	<10	<50	<100	<20	<5	100	<10	<10	5	<20	150	<20	10
23	6/3	<5	<10	5	10	<25	<10	<10	<50	<100	<20	<5	150	<10	<10	5	<20	170	<20	15
24	6/5	<5	<10	15	15	<25	<10	<10	<50	<100	<20	<5	500	<10	<10	5	30	600	<20	30
25	1/3	<5	10	<5	20	50	30	<10	100	<100	<20	5	600	<10	<10	5	10	300	<20	25
26	1/5	<5	15	5	20	40	10	<10	50	<100	<20	5	700	<10	<10	5	100	400	<20	30
27	1/18	10	15	10	10	<25	50	<10	<50	<100	<20	<5	500	<10	<10	5	1000	500	<20	10
28	2/2	<5	10	5	10	50	30	<10	<50	<100	<20	5	600	<10	<10	5	900	400	<20	30
29	2/7	<5	10	5	10	25	50	<10	<50	<100	<20	5	700	<10	<10	5	1500	400	<20	30
30	2/11	<5	10	<5	30	<25	<10	<10	<50	100	<20	20	300	<10	<10	5	70	<20	<20	15

contd.....

S.No.	Sam.No.	Li	Mn	Cu	Pb	Zn	Ni	Co	Ba	Sr	Sn	Mo	Cr	In	Ge	Be	Zr	V	Y	Ga
31	3/1	<5	<10	5	<10	50	<10	<10	<50	<100	<20	<5	200	<10	<10	<5	100	100	<20	10
32	3/7	10	<10	10	<10	<25	25	<10	300	100	<20	<5	300	<10	<10	5	400	250	30	20
33	3/10	<5	15	10	20	<25	30	<10	50	<100	<20	<5	500	<10	<10	5	500	300	20	15
34	4/2	10	<10	5	<10	25	<10	<10	<50	<100	<20	5	150	<10	<10	5	100	300	20	5
35	4/8	<5	20	<5	10	25	15	<10	<50	<100	<20	15	700	<10	<10	<5	150	150	<20	15
36	4/10	5	10	10	10	<25	25	<10	200	<100	<20	5	300	<10	<10	5	300	200	20	15
37	4/19	<5	15	<5	<10	25	15	<10	<50	<100	<20	15	700	<10	<10	<5	300	600	<20	10
38	5/1	<5	15	5	30	25	40	15	<50	<100	<20	20	700	<10	<10	<5	300	600	<20	10
39	6/2	<5	20	5	<10	50	<10	<10	<50	<100	<20	<5	150	<10	<10	<5	70	400	<20	10
40	1/9	<5	10	10	10	25	15	<10	400	100	<20	<5	<5	<10	<10	5	20	250	30	10
41	1/12	<5	10	15	<10	25	40	<10	<50	<100	<20	<5	400	<10	<10	<5	700	150	<20	20
42	2/1	<5	10	15	<10	25	70	<10	<50	<100	<20	5	400	<10	<10	<5	700	150	<20	20
43	2/16	<5	10	10	15	<25	<10	<10	400	<100	<20	<5	250	<10	<10	<5	50	150	20	10
44	3/6	10	10	15	15	25	15	<10	50	<100	<20	<5	5	<10	<10	<5	200	250	30	20
45	3/12	10	10	<10	10	30	50	<10	100	<100	<20	<5	50	<10	<10	<5	100	200	20	25
46	4/5	<5	10	15	<10	25	15	<10	50	100	<20	<5	200	<10	<10	<5	70	150	<20	15
47	4/20	<5	10	10	10	25	15	<10	300	100	<20	<5	250	<10	<10	5	500	250	20	10
48	5/5	<5	10	10	15	30	60	10	200	100	<20	10	50	<10	<10	<5	500	200	30	15

contd.....

S.No.	Samp. no.	Li	Mn	Cu	Pb	Zn	Ni	Co	Ba	Sr	Sn	Mo	Cr	In	Ge	Be	Zr	V	Y	Ga
49	6/4	10	10	20	20	25	25	<10	300	100	<20	10	400	<10	<10	5	150	250	25	10
50	2/8	<5	40	10	10	100	<10	<10	<50	<100	<20	5	700	<10	<10	5	700	400	<20	20
51	2/9	<5	40	5	10	100	<10	<10	<50	<100	<20	5	800	<10	<10	5	700	400	<20	20
52	1/19	10	400	10	10	30	50	20	500	700	<20	<5	200	<10	<10	<5	150	100	<20	7
53	1/21	10	300	10	20	30	20	15	800	800	<20	<5	200	<10	<10	<5	170	70	<20	5
54	2/14	10	300	10	10	50	30	20	800	700	<20	<5	250	<10	<10	<5	150	100	<20	5
55	2/17	10	400	10	15	50	30	20	700	1700	<20	<5	200	<10	<10	<5	150	100	<20	7
56	3/15	10	400	5	20	50	25	10	700	800	<20	<5	200	<10	<10	<5	150	70	<20	5
57	3/17	10	300	5	10	50	30	30	1000	1500	<20	10	300	<10	<10	<5	100	150	<20	5
58	4/21	10	400	10	10	50	50	15	1500	1700	<20	10	200	<10	<10	<5	170	150	<20	7
59	5/7	10	300	5	15	20	20	15	<50	700	<20	<5	250	<10	<10	<5	130	150	<20	5
60	6/6	10	300	5	15	20	5	30	700	700	<20	10	300	<10	<10	<5	200	50	<20	5

Samples Nos.
1-24 Baxuites
25-39 Laterites
40-49 Lithomargic clay
50-51 Phosphatic Bauxites
52-60 Parent Rocks

TABLE XII :- REPRESENTS CONCENTRATION RATIO OF ELEMENTS IN DIFFERENT ZONES OF BAUXITE PROFILE AS COMPARED TO THE PARENT ROCKS.

ELEMENT		RATIO OF CONCENTRATION		
		LITHOMORGIC CLAY	BAUXITE	LATERITE
Concentrated >Al	Ga	2.8	2.5	3.07
	V	1.9	1.9	3.03
	Zr	1.9	1.9	2.5
	Cr	-	2.3	2.0
	Al	1.8	3.9	1.2
Concentrated <Al	Cu	1.6	-	-
Depleted	Li	0.4	0.5	-
	Mn	0.4	0.5	-
	Pb	0.7	0.7	0.8
	Zn	0.02	0.02	0.02
	Ba	0.02	0.03	0.08
	Sr	0.09	0.04	0.09

PLATES

PLATE-I

Figure-1 shows an outline of Shevaroy hill which is roughly oval or elliptical in shape.

PLATE I

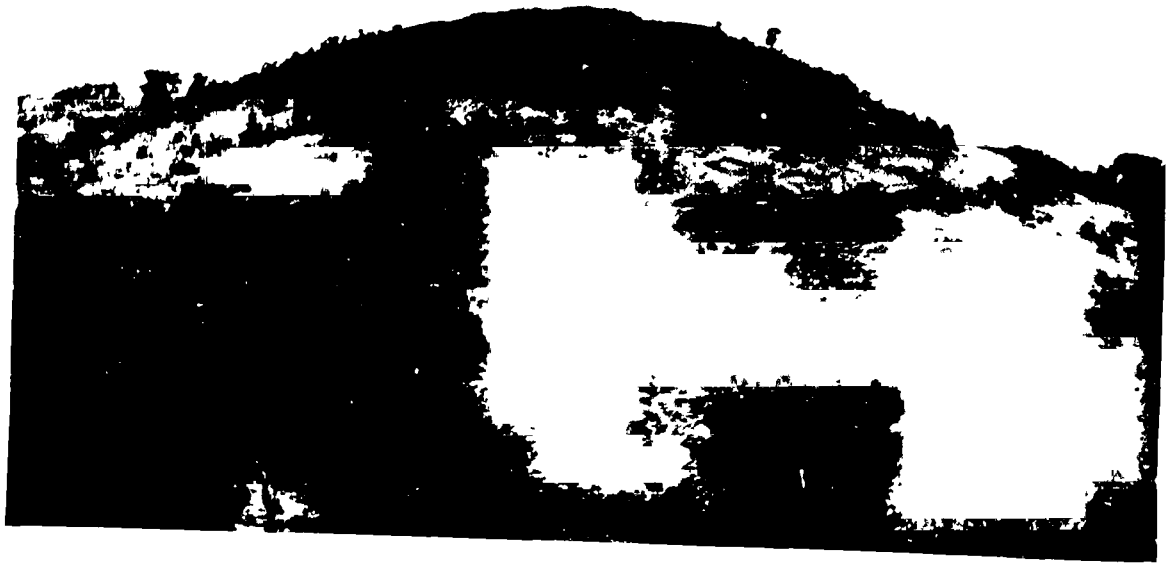

FIG. I

PLATE-II

Figure-1 shows the analytical work in progress on Atomic Absorption Spectrophotometer.

Figure-2 shows the mineral studies on an X-ray instrument.

PLATE II

FIG. 1

FIG. 2

PLATE-III

Figure-1 shows irregular and gradational contact between dark reddish laterite and aluminous laterite in the bauxite profile.

Figure-2 shows presence of the various minerals in the charnockite and effect of crushing and tectonism by slight stretching on quartz grain.

PLATE III

FIG. 1

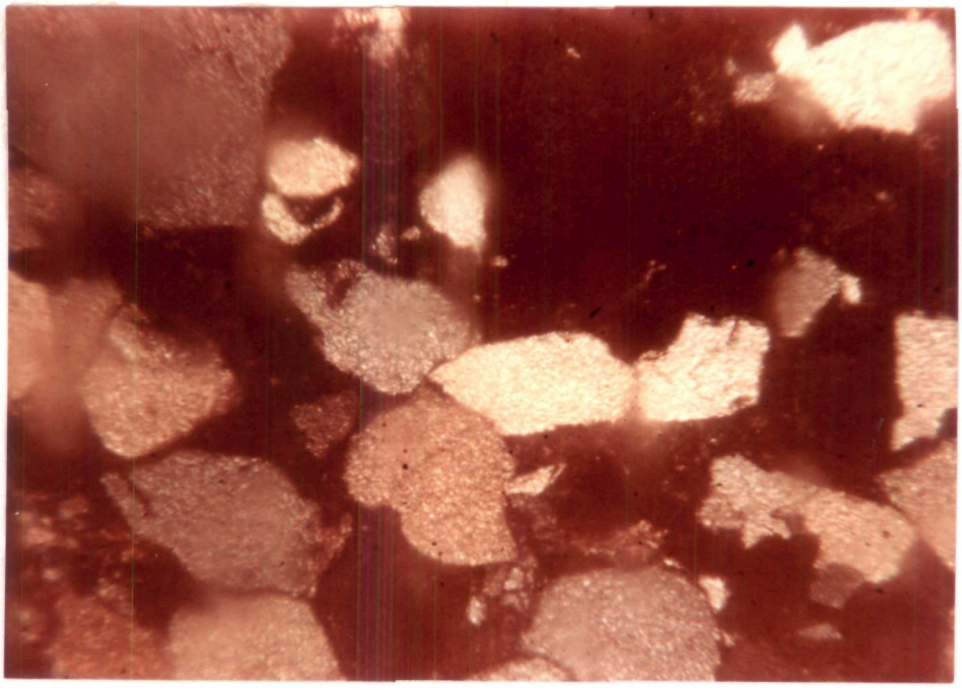

FIG. 2

PLATE-IV

Figures-1, 2, 3 & 4 show the X-ray diffraction photographs in strip forms.

PLATE IV

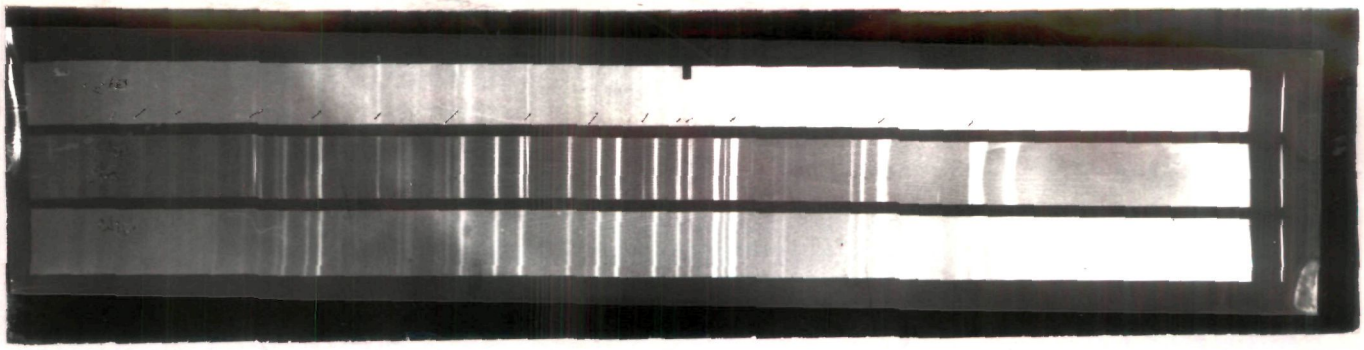

FIG. 1

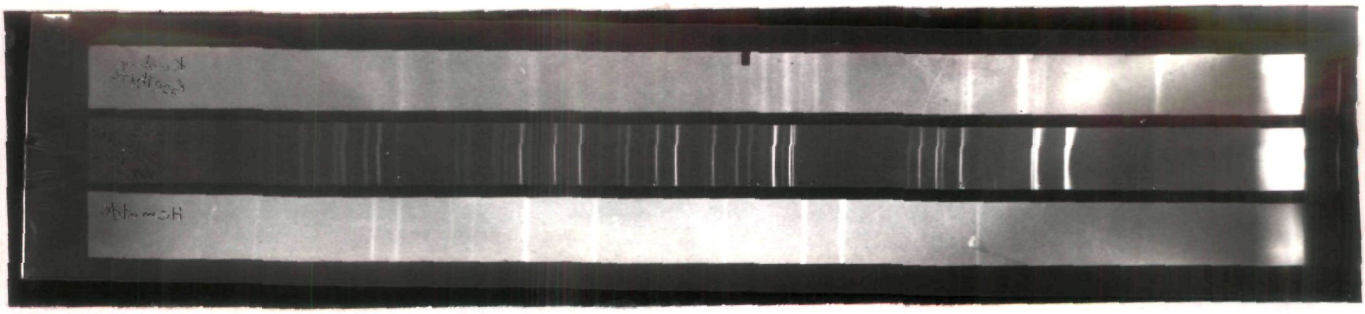

FIG. 2

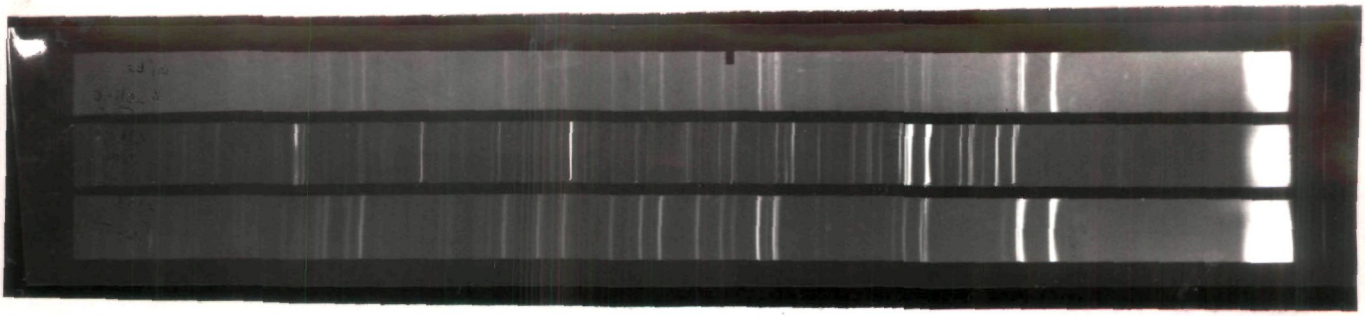

FIG. 3

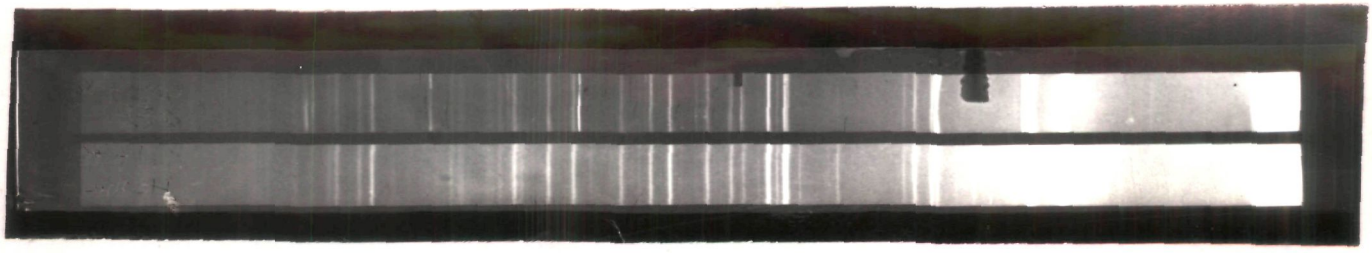

FIG. 4

PLATE-V

Figures-1, 2, 3 & 4 show the X-ray diffraction photographs in strip forms.

PLATE V

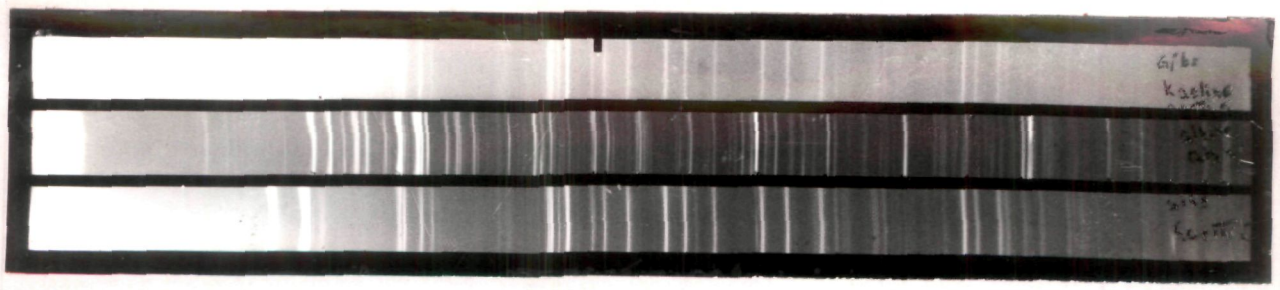

FIG. 1

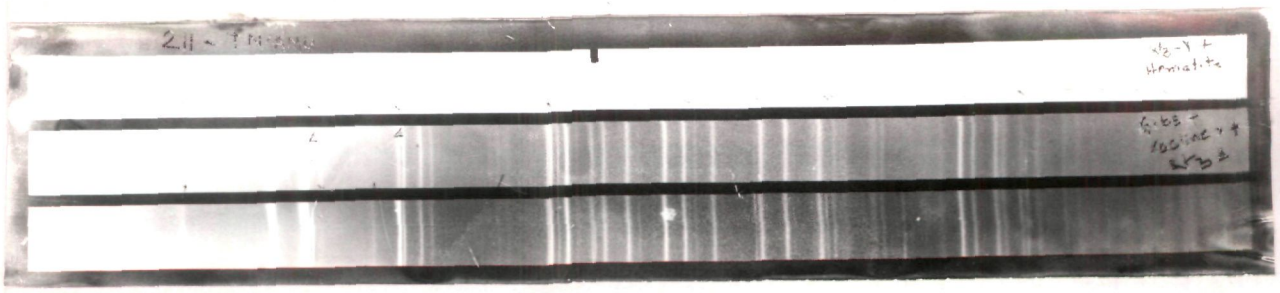

FIG. 2

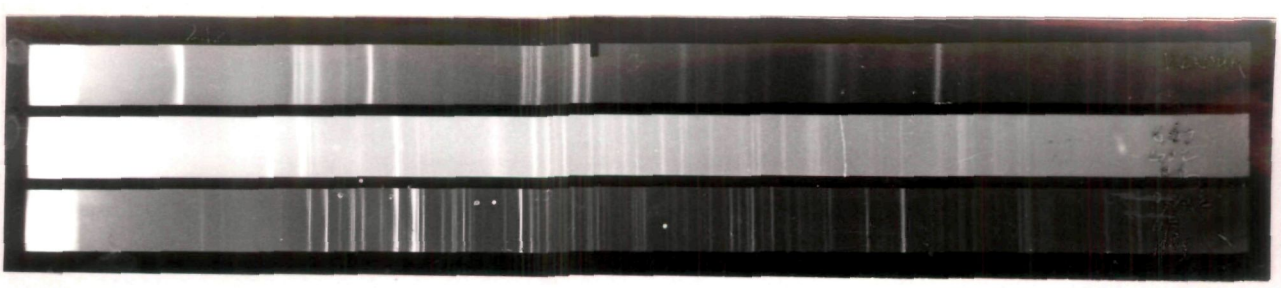

FIG. 3

PLATE-VI

Figure-1 shows the parent rock composition in addition to garnet (gondite).

Figure-2 shows microcrystalline and large tabular crystals of gibbsite with interstial patches of goethite. Exhibit polysynthetic twinning with well defined twin lamellae. Small anhedral grains, probably of anatase are also present.

PLATE VI

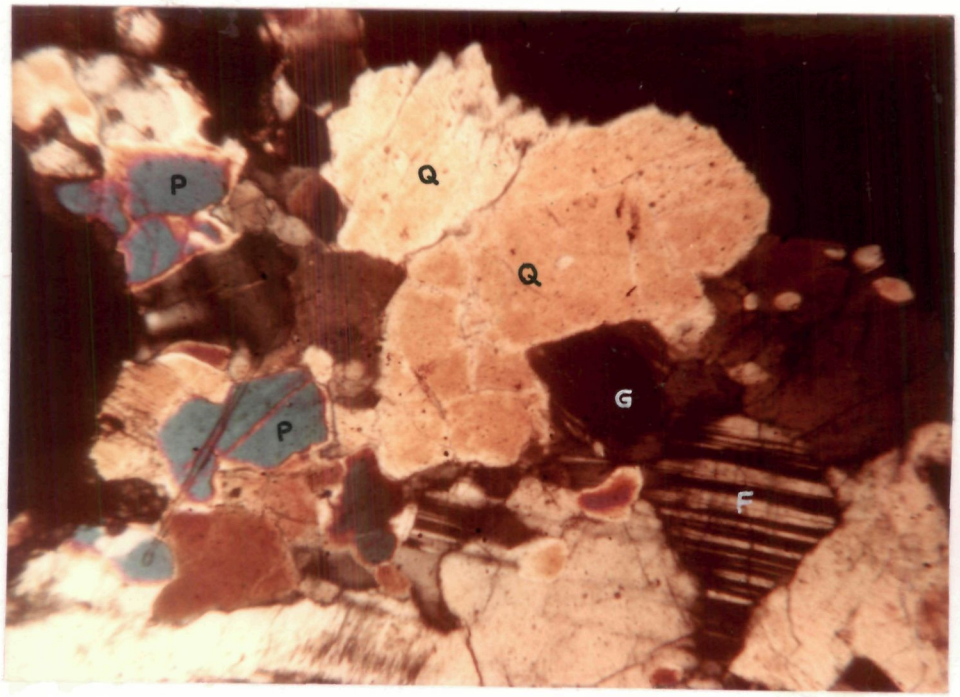

FIG. 1

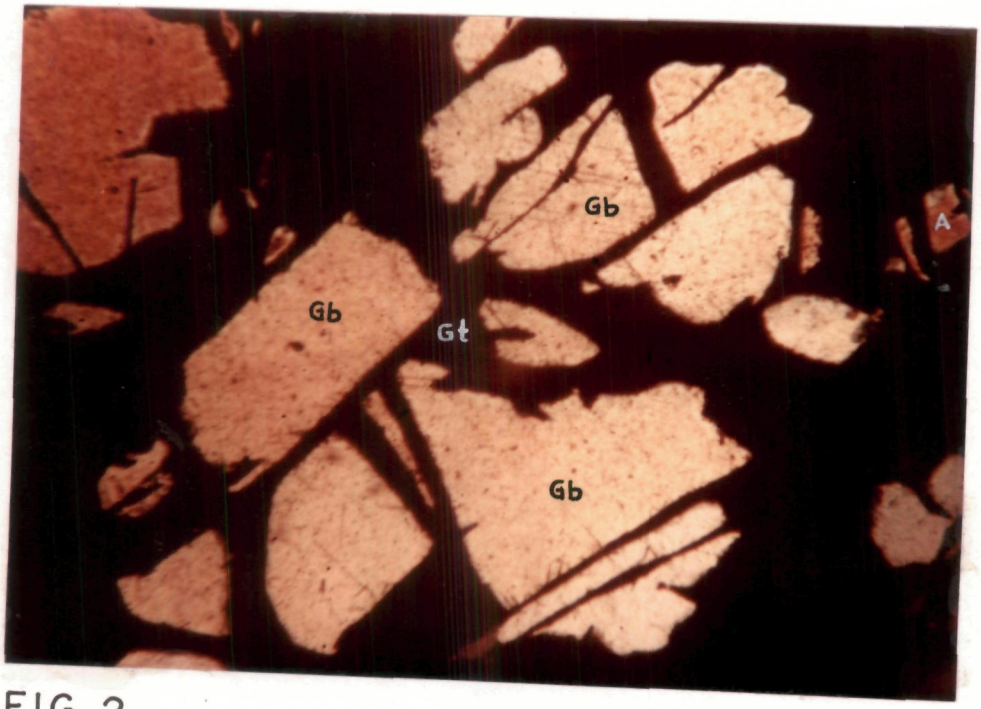

FIG. 2

PLATE-VII

Figure-1 shows fine grained microcrystalline aggregates of clay minerals.

Figure-2 shows angular grains, characterized by blood red colour in reflected light, crevices are shown filled up with clay or limonitic matrix that reveal secondary relationship with other constituents.

PLATE VII

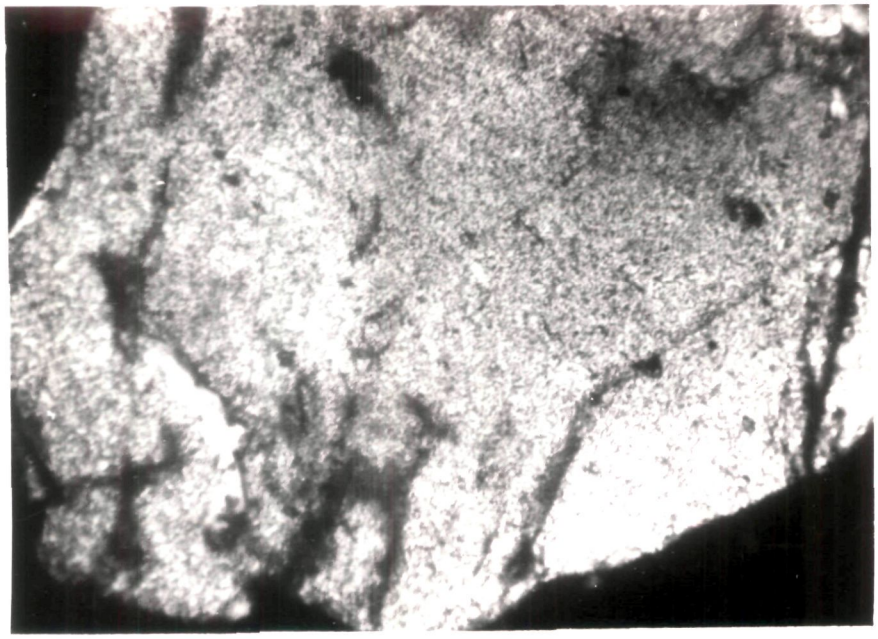

FIG. 1

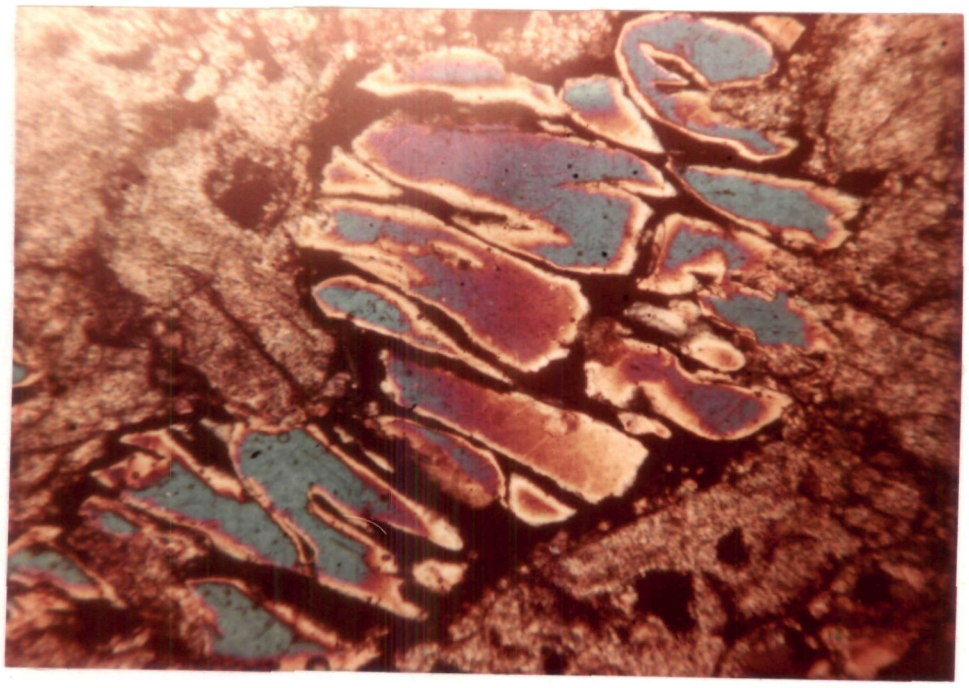

FIG. 2

PLATE-VIII

Figure-1 shows the disseminated grains of the phosphate mineral (Variscite-Ferrian) in the form of clustures, admixed with iron and silica.

Figure-2 shows amorphous silica as shapeless patches having concentric rims of gibbsite and limonite.

PLATE VIII

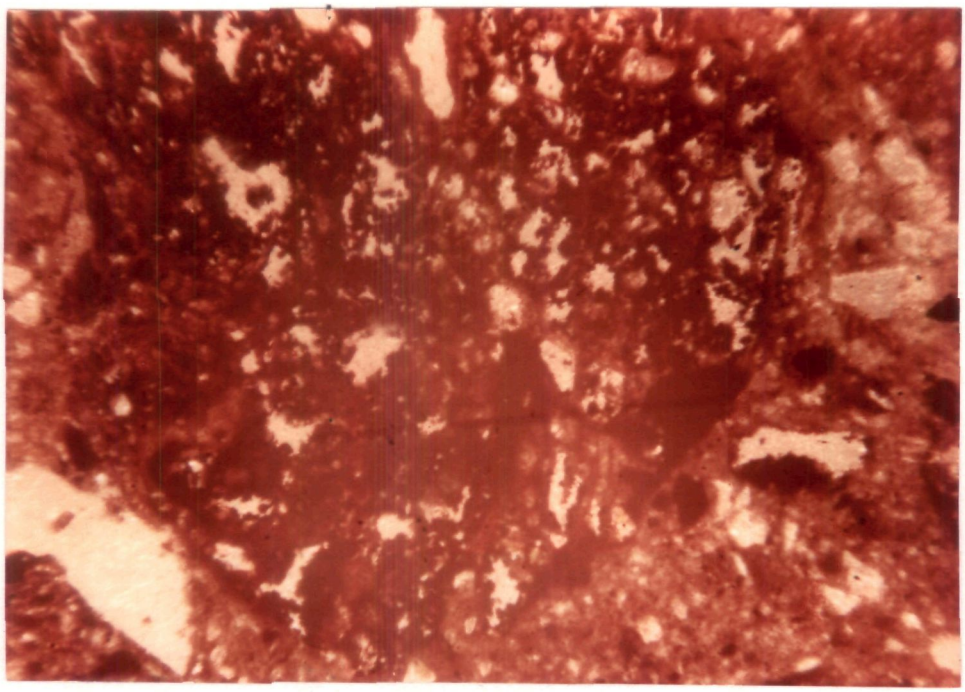

FIG. 1

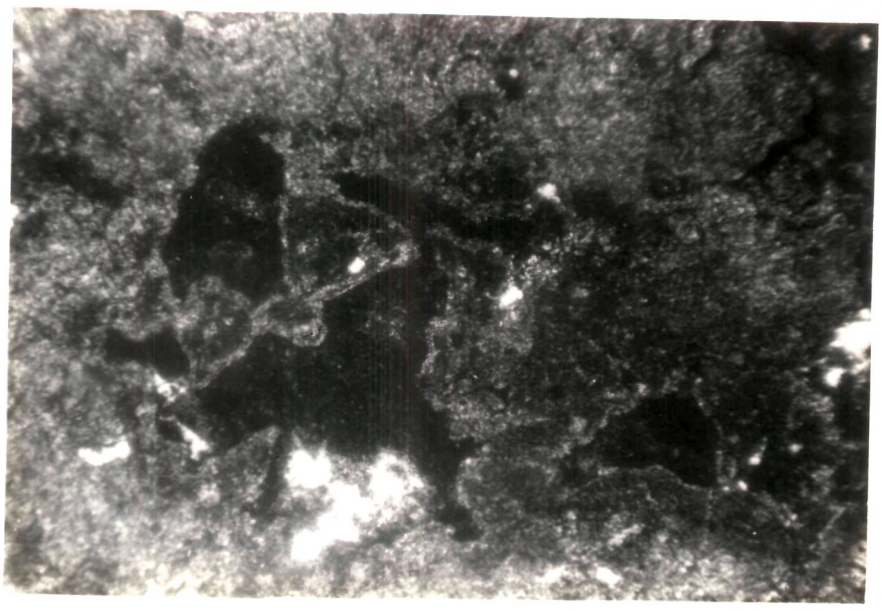

FIG. 2

PLATE-IX

Figure-1 shows a variety of laterite in which innumerable cavities are filled up by clay or opaque secondary iron mineral.

Figure-2 shows a patchy appearance in bauxites due to the close association of transluscent to opaque minerals and aggregates shape of gibbsite. Goethite and kaolinite are seen as interstitial matrix.

PLATE IX

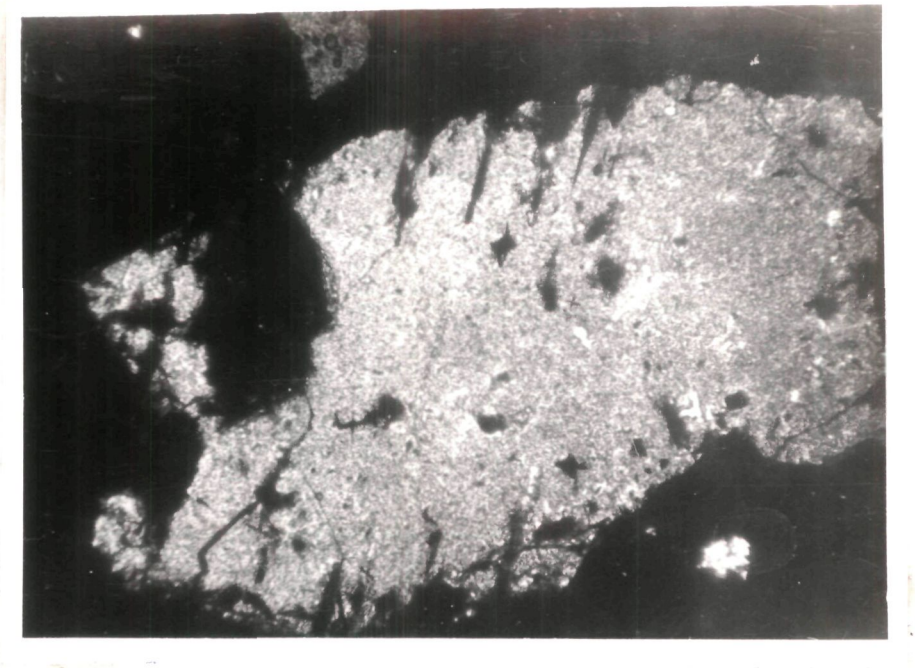

FIG. 1

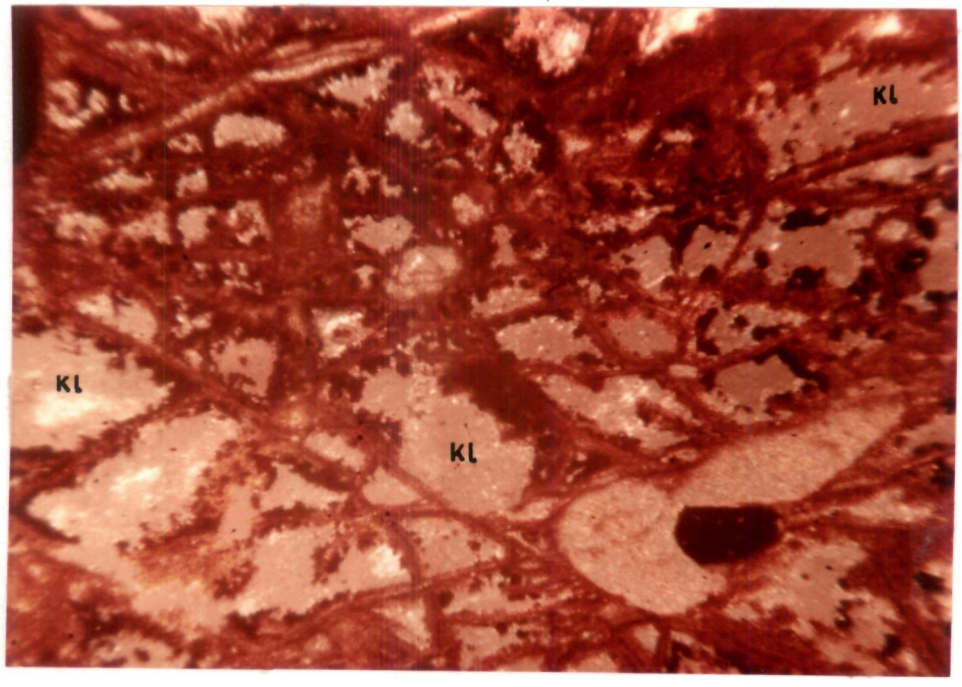

FIG. 2

PLATE-X

Figure-1 shows lithomargic clay with fine laminations and inclusions. These perhaps reveal patchy distribution of deep, red iron oxides.

Figure-2 shows replacement and distribution of primary minerals, wherein ferro-magnesian minerals are less affected by weathering.

PLATE X

FIG. 1

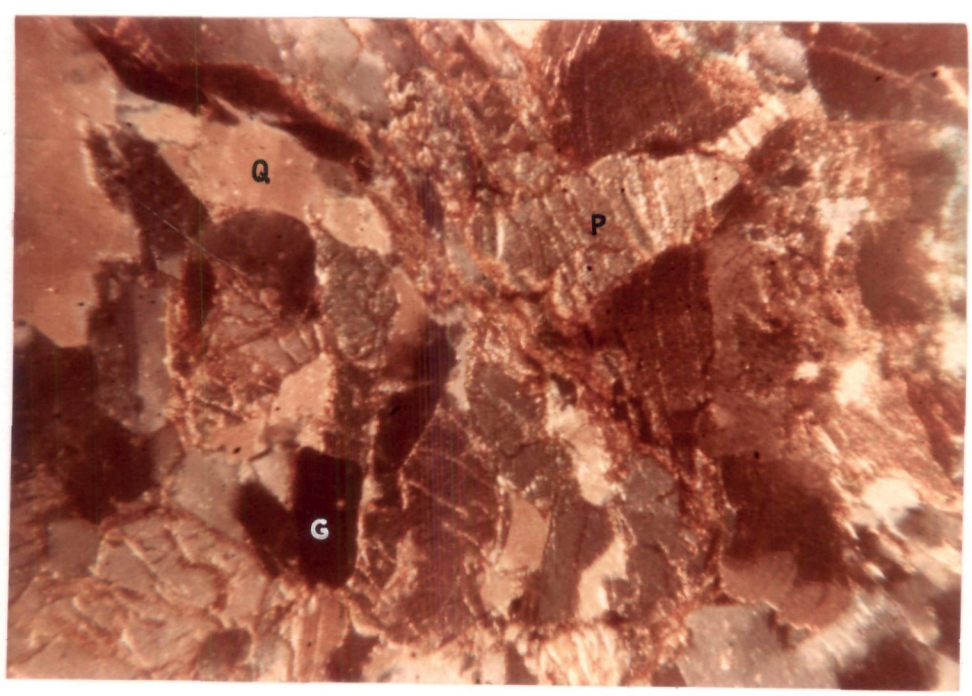

FIG. 2

PLATE-XI

Figure-1 shows retention of original rock texture, with alternate banding of dark and light coloured minerals.

Figure-2 shows the isotropic substances which could either be gels of aluminium hydroxide from clay minerals of incomplete development.

PLATE XI

FIG. 1

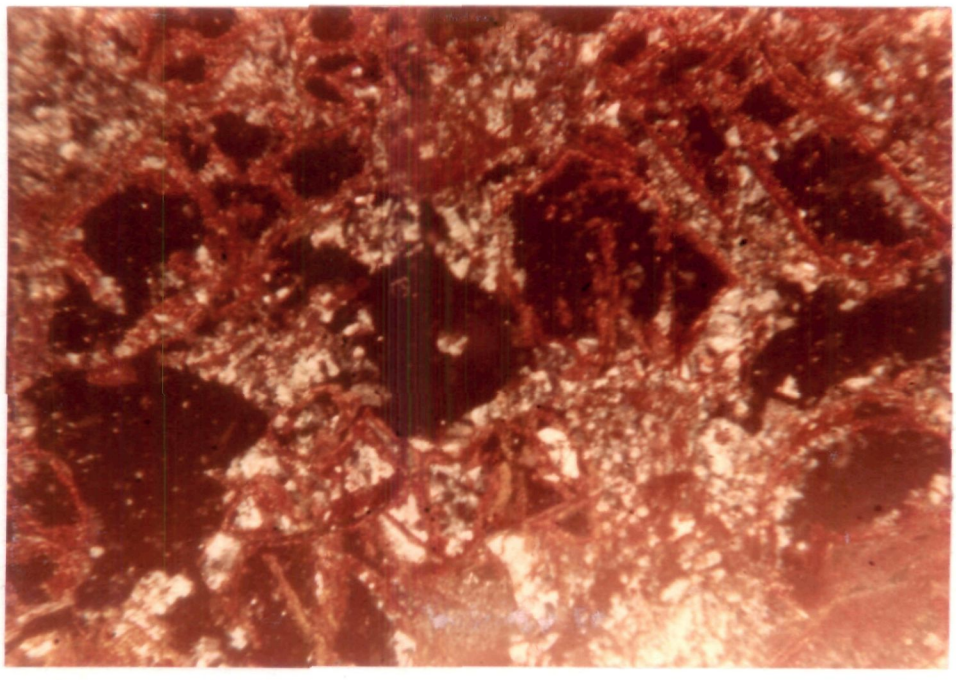

FIG. 2

PLATE-XII

Figure-1 shows the advanced stage of weathering and alteration in which replaced feldspars form dense motted structure. Relict grains of pyroxenes and feldspars are well observed.

Figure-2 shows alteration of grain and subgrain of quartz. The width of cracks has increased as displayed by the larger areas, filled by gibbsite and goethite matrix. It also indicate replacement of feldspars.

PLATE XII

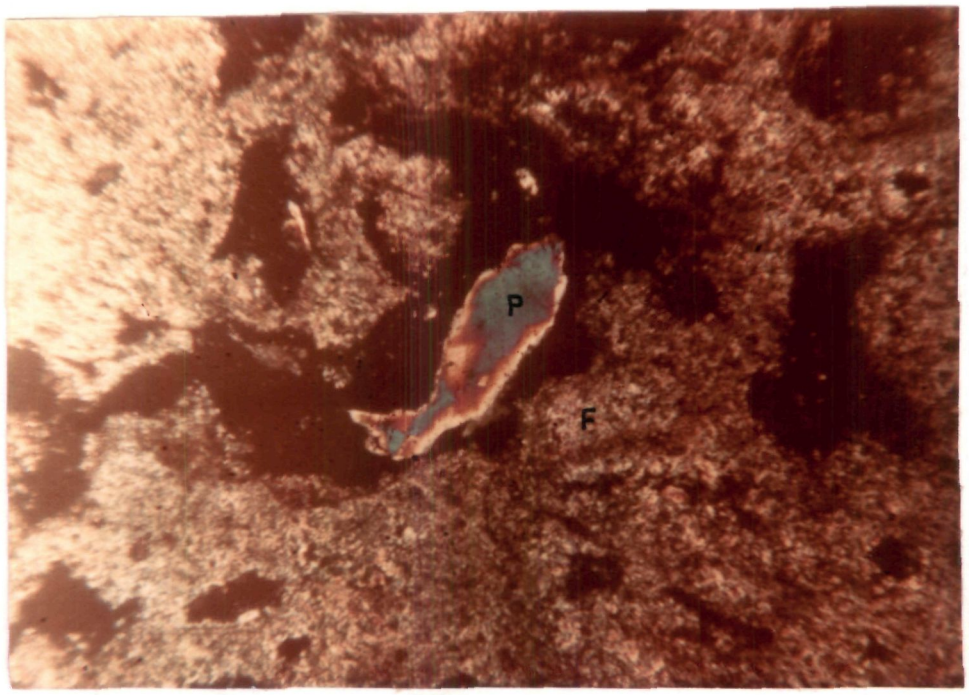

FIG. 1

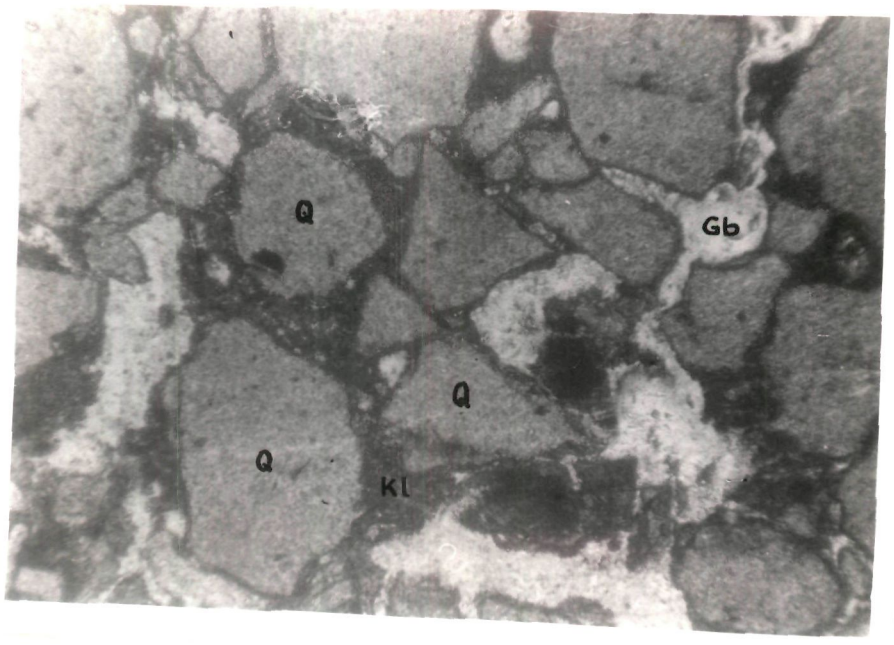

FIG. 2

PLATE-XIII

Figure-1 shows the difference in textural features in the bauxites of central and southern India.

Figure-2 shows the development of cavities or cavernous bauxites with infilling of secondary matrix.

PLATE XIII

FIG. I

PLATE-XIV

Figure-1 shows the various types of bauxite samples. Laterite (Cavernous aluminous laterite with limonitic matrix in the cavities). It is earthy and compact in nature.

Figure-2 shows cavernous laterite in which the cavities are filled with black matrix of hematitic iron and in another sample development of microcrystalline gibbsite of white or pinkish colour is seen.

INDEX

Q = Quartz
F = Feldspar
G = Garnet
Gb = Gibbsite
Gt = Goethite
P = Pyroxene
Kl = Kaolinite

PLATE XIV

FIG. 1